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THE

PHYSICAL REVIEW.

WITH FURTHER REFERENCE TO THE FORCE BETWEEN TWO REVOLVING ELECTRONS AT A GREAT DISTANCE.

By Albert C. Crehore.

IN a paper[1] published in June, 1917, reasons were given for the conclusion that the current form of electromagnetic equations requires modification in a fundamental manner. Briefly, it appears from a consideration of the mechanical force between two revolving electrons in small circular orbits, the centers being a great distance apart, that the force between two bodies of gross matter at a great distance apart must be immensely greater than the known force between them, namely the gravitational force, assuming, of course, that there was no error in the somewhat involved processes of applying the electromagnetic equations to the case.

In a recent paper[2] G. A. Schott has examined in much detail the investigation in the paper above referred to, and says in his opening paragraph "hence (Crehore) concludes, quite legitimately if his result be correct, that the fundamental equations of the accepted electron theory require substantial modification" and "It is obviously imperative that Crehore's result be either verified or disproved." In the second paragraph he says: "The following investigation is based on Crehore's equations for the electric part of the mechanical force,"[3] "which have been verified, except some obvious misprints,[4] *e. g.*, a_2 for a_1 in the last term of (49)." Above in the same paragraph Schott remarks: "Thus it is desirable to take the magnetic effect into account *ab initio*, although it will be found to be inappreciable on the average for an amorphous medium but not necessarily so for a crystal."

[1] A. C. Crehore, Phys. Rev., Sec. Ser., Vol. IX., p. 445, June, 1917.

[2] G. A. Schott, Phys. Rev., Sec. Ser., Vol. XII., p. 23, July, 1918.

[3] *Loc. cit.*, pp. 453, 454—this referring to the June, 1917, paper above mentioned.

[4] It is hoped that Dr. Schott will publish all of the errors in the expression for the instantaneous force that he alludes to, in order that this important equation may be available in its complete form, having been verified.

In reply to this last criticism it should be stated that the complete instantaneous force, including the magnetic component, had been obtained and averaged in a similar manner to the electric component prior to the time of publishing the June, 1917, paper, but it was not published partly because of its length, and partly because each magnetic term in the final average was affected by a common factor in powers of β higher than the square. So long as terms were being obtained from the electric component having the greater factor β^2, they were large compared with any terms obtained from the magnetic component. The quantity, $\beta_1\beta_2^3$, is a common factor of the equation (48), p. 36 of the Schott paper,[1] which is his final expression for the time average of the magnetic component. The importance of the equation for the instantaneous force with no terms whatever omitted is so great that the equation for the magnetic component, supplementing the electric already published in equations (48), (49) and (50), June, 1917,[2] is given below in an appendix. In the case of coaxial rings of electrons, where the instantaneous and the average forces are identical, this equation has a wider application than to possible long range gravitational forces. As evidence that the complete force had been obtained, equation (92), p. 469, of the June, 1917, paper may be cited. This gives the complete force, including all terms from both the electric and the magnetic parts exerted upon any selected electron in a ring of electrons due to any other electron in the same ring.

The present paper is offered as a preliminary reply to the Schott paper referred to. It is submitted before there has been opportunity to make a careful study of the suggested corrections as to averaging, which at best is a laborious process, and is submitted principally because the deductions that Schott draws from his own formula fall short of the mark. In his concluding remarks, p. 37,[3] Schott states that "from an experimental point of view, however, the deviation is not of much moment, for it is easily seen by expanding the function of β_2 in (50) that the first power which occurs is the fourth, so that, if β_2 be as large as .01, the relative deviation is less than the hundred millionth. For this reason I shall not pursue the matter further here." This statement refers to the previous sentence, in which it is pointed out that the average force of the second electron acting upon the first differs from that of the first acting upon the second, the law of action and reaction not holding true, as Schott states, except to a first approximation.

The only interpretation that I can give to these remarks is that Schott

[1] *Loc. cit.*
[2] *Loc. cit.*
[3] *Loc. cit.*

is making a comparison between the magnitude of the terms containing β, which vary with the value of β, and the constant term, namely the electrostatic force, which does not vary with any change of speed. (See his equation for the average force repoduced in (1) below.) It is manifestly improper to make such a comparison when applying these results to the *atoms* of matter, as was done in the June, 1917, paper referred to. The obtaining of the force between two revolving *electrons* is but one step in the process of finding the force between two *atoms*, supposing these atoms to consist of rings of electrons revolving around a positive nucleus located at the center of the orbits, and having a charge equal to the sum of the charges on the electrons but of opposite sign, as in a neutral atom.

To place the equation under discussion before us, Schott's result, his equation (50) p. 37,[1] is reproduced here, after making an obvious correction in the denominator of the last term under the logarithm, making β^2 read β_2, namely

$$(\mathbf{F}\cdot\mathbf{r})/r = -\frac{e_1e_2}{r^2}\left\{1+\beta_2^2\left(\frac{1}{1-\beta_2^2}-\frac{1}{2\beta_2}\log\frac{1+\beta_2}{1-\beta_2}\right)\right\}. \qquad (1)$$

Adopting Schott's suggestion, and expanding this in powers of β_2, we find

$$\frac{1}{2\beta_2}\log\frac{1+\beta_2}{1-\beta_2} = 1+\frac{1}{3}\beta_2^2+\frac{1}{5}\beta_2^4+\frac{1}{7}\beta_2^6+\ldots \qquad (2)$$

and

$$\frac{1}{1-\beta_2^2} = 1+\beta_2^2+\beta_2^4+\beta_2^6+\ldots, \qquad (3)$$

and, finally, the complete force equivalent to (1) is

$$(\mathbf{F}\cdot\mathbf{r})/r = -\frac{e_1e_2}{r^2}\left(1+\frac{2}{3}\beta_2^4+\frac{4}{5}\beta_2^6+\frac{6}{7}\beta_2^8+\ldots\right). \qquad (4)$$

When the effect of the positive nuclei are taken into the account in summing up the forces between the various component parts of two *atoms*, all the electrostatic terms cancel out, and require no further consideration, the whole force at great distances between such atoms being due solely to the terms involving the speed of the revolving electrons, the β-terms in (1) or (4) above.

Referring again to the paper of June, 1917, top of page 456, it is stated that the electrostatic terms were omitted in taking the average force for the reason that they contribute nothing to the inverse square of the distance terms under discussion, when the effect of the positive charge of the atoms is included so as to get the force between atoms instead of

[1] *Loc. cit.*

electrons only. Schott, however, has carried these electrostatic terms through the averaging process from the beginning, and they give rise to the constant term, $-e_1e_2r^{-2}$, in (1) above, which should now be omitted in making any deductions about atoms or gross matter. Making this omission, and also making a sufficiently close approximation to the value of the force by omitting all powers of β higher than the fourth, we simplify Schott's result, as applied to a pair of electrons in neutral atoms, from (4) to be

$$(\mathbf{F}\cdot\mathbf{r})/r = -\tfrac{2}{3}e^2\beta_2^4 r^{-2}. \tag{5}$$

Comparing this with the result obtained in June, 1917, the difference is principally in the sign and in the substitution of β_2^4 for β_2^2. As far as the law of action and reaction is concerned, the difference is greater with β_2^4 than with β_2^2. If we substitute β_1 for β_2, and take the ratio of the forces, it is evidently equal to $(\beta_1/\beta_2)^4$. If β_1 is nearly twice as large as β_2, the ratio is nearly 16 to 1, and the forces of Action and Reaction are not only not equal and opposite to a first approximation, as Schott states, but they are not even of the same order of magnitude. The ratio between them is greater than it would be if β^2 appeared in the formula instead of β^4.

An important criticism of the formula, however, is connected with the magnitude of the force between two pieces of matter at great distances. If we had β^2 instead of β^4, as formerly, the magnitude of the force at great distances exceeds the known force of gravitation in an immense ratio, about 10^{31}. The change from β^2 to β^4, assuming β^2 to be of the order of 10^{-4}, only reduces this ratio from 10^{31} to about 10^{27}, the two figures being so nearly alike that there is little choice between them. Whether the formula calls for a repulsive force or an attraction makes no difference in this argument as to the magnitude. We know that no such force exists, and the argument for a revision of the fundamental electromagnetic equations remains valid, taking Schott's results as to averaging to be correct.

This matter of the magnitude of the force may, perhaps, best be shown by a special example. In order not to raise the question of synchronism between the two electrons, let us select two atoms, the one having a single ring of two electrons and the other of four. If the two atoms were supposed to be alike, it is reasonable to take the speeds the same for each, but Schott does not claim that his formula applies to two synchronous electrons. It may be remarked, however, on this point I have found that, when complete rings of equally spaced electrons are concerned, the formula for synchronous electrons reduces to precisely the same form as for incommensurable velocities, since all the terms involving the

phase angles disappear when rings are taken, and we obtain the same result as without synchronism. Not to raise the question, however, let us calculate the force on atom A, a two electron single ring atom, due to atom B, a four electron single ring atom, the speed of each electron in A being β_1, and in B, β_2. According to (5) the force of the four electrons in B upon one electron in A is 4 times the expression in (5). Similarly, the force of the four upon the second electron in A is 4 times (5), making a total of 8 times (5).

On the other hand, the force of the two electrons in A upon one in B is two times (5), writing β_1 instead of β_2. The total force of the two in A upon the four electrons in B is then eight times (5) writing β_1 instead of β_2. We have then

$$\text{Total force of } B \text{ on } A = -\tfrac{16}{3} e^2\beta_2^4 r^{-2}. \tag{6}$$

$$\text{Total force of } A \text{ on } B = -\tfrac{16}{3} e^2\beta_1^4 r^{-2}. \tag{7}$$

If it is permitted, in making an approximation to the speeds of the electrons, to adopt the approximate formula (3), page 14, PHYSICAL REVIEW, July, 1918, for the speed of any ring of electrons, and a moderate error in the estimated speed cannot affect our argument at all, namely

$$\beta^2 = p\frac{\pi^2 e^4}{c^2 h^2}, \tag{8}$$

we have for the fourth power of the speed of each electron in atom A

$$\beta_1^4 = 4\frac{\pi^4 e^8}{c^4 h^4}, \tag{9}$$

and in atom B

$$\beta_2^4 = 16\frac{\pi^4 e^8}{c^4 h^4}. \tag{10}$$

whence (6) and (7) become

$$F_{BA} = -\frac{256}{3}\frac{\pi^4 e^{10}}{c^4 h^4} r^{-2}, \tag{11}$$

$$F_{AB} = -\frac{64}{3}\frac{\pi^4 e^{10}}{c^4 h^4} r^{-2}. \tag{12}$$

We shall also make a further assumption that the two-electron atom, A, represents hydrogen, and the four electron atom, B, helium. This assumption also will not affect our argument where such a large ratio as 10^{27} is concerned. According to the law of gravitation the average force between one atom of hydrogen and one of helium is

$$F = k m_H m_{He} r^{-2}. \tag{13}$$

The mass of the helium atom is approximately four times that of the hydrogen atom, so that, in terms of m_H, (13) becomes

$$F = 4km_H^2 r^{-2}. \tag{14}$$

Taking the smaller of the two forces, namely that in (12), for the purpose of comparison with the magnitude of the gravitational force, and taking the ratio, we have

Ratio of the calculated force to the actual gravitational force

$$= \frac{16}{3} \frac{\pi^4 e^{10}}{km_H^2 c^4 h^4}. \tag{15}$$

It was pointed out in the paper above referred to, equation (9), p. 15, July, 1918, that a very exact numerical value of the gravitational constant, k, is given by the expression,

$$k = \frac{p^4}{3K} \frac{m_0}{m_4^2} \frac{\pi^4 e^{10}}{c^4 h^4}, \tag{16}$$

in which $K = 1$, is the specific inductive capacity, and $p = 2$, the number of electrons in the hydrogen atom. m_0 is the mass of the negative electron at slow velocities. With these values, we have

$$k = \frac{16}{3} \frac{m_0}{m_H^2} \frac{\pi^4 e^{10}}{c^4 h^4}. \tag{17}$$

Upon substitution of this correct numerical value of the Newtonian constant, k, in (15), the expression reduces to

Ratio of calculated force to the gravitational force

$$= 1/m_0 = 1/.90 \times 10^{-27} = 1.11 \times 10^{27}. \tag{18}$$

The ratio would be four times greater than this if we had used the larger of the two forces as given in (11) above. This completes the special example, and shows that the force given by the Schott formula is greater than the gravitational force by a factor of about 10^{27}, as was pointed out before considering the example.

In conclusion, it has, we believe, been clearly shown that the application which Schott has made of his final result, equation (50) of his paper, or (1) above, to gross matter is incorrect. The positive nuclei of the atoms must be taken into the account as well as the revolving electrons. Whether or not the matter has been properly treated above in the simple omission of the constant, which is independent of the speed remains to be seen. It seems that any system of electromagnetic equations that does not make the mechanical force of one revolving electron acting upon a second exactly equal and opposite to that of the other on the one, thus strictly conforming to the law of action and reaction is pretty certain to lead to insuperable difficulties when applied to the accepted forms of atoms. It is difficult to believe that the average mechanical force on

the first electron due to the second is entirely independent of the state of motion of the first electron. It seems as if its motion must in some way alter the average force upon it due to the second electron independent of any change that may be taking place in the motion of the second electron, and yet this is contrary to the Larmor-Lorentz form of theory.

Let us admit for the moment that a form of theory is possible that makes the average mechanical force between the two electrons a function of the product of the two speeds instead of the speed of one of the charges only. Then, when either of the two speeds vanishes the product vanishes, and the force between a revolving negative electron and a stationary positive charge is the same whether we consider the force of the one on the other or the other on the one, and is equal simply to the electrostatic terms. In the case of two revolving electrons the force of the one on the other would be the same as the other on the one, the Law of Action and Reaction being preserved way down to the ultimate constituent parts of the atoms and of gross matter, namely the electrons.

It seems as if the finding of a simple expression for the Newtonian constant given in a former paper, equation (9),[1] has some bearing upon this question, especially because all of the laws of gravitation have been shown to follow from the premises assumed. It is very evident that the least change in the fundamental equations of electromagnetic theory may easily switch the resulting force at great distances about from a repulsion to an attraction, the force being so small that the residual may take either a positive or a negative sign. The chief point that has now been established is that there are existing forces at great distances that vary inversely as the square of the distance, the gravitational law, as demanded by the present unmodified form of theory. Not much attention has been given to these forces in the past, and it seems as if it was not realized that they existed, as demanded by the accepted theory.

[1] *Loc. cit.*

ON THE SPECULAR REFLECTION FROM ROUGH SURFACES.

BY T. K. CHINMAYANANDAM.

IT is well known that matt surfaces behave nearly in the same way as polished reflectors, when the incident rays are of great wave-length or fall very obliquely on the surface. In a paper published in the PHYSICAL REVIEW for January, 1916, A. F. Gorton has followed up the work of Lord Rayleigh[1] and T. J. Meyer[2] on this subject, and has given several curves showing the relative reflecting power of surfaces of ground

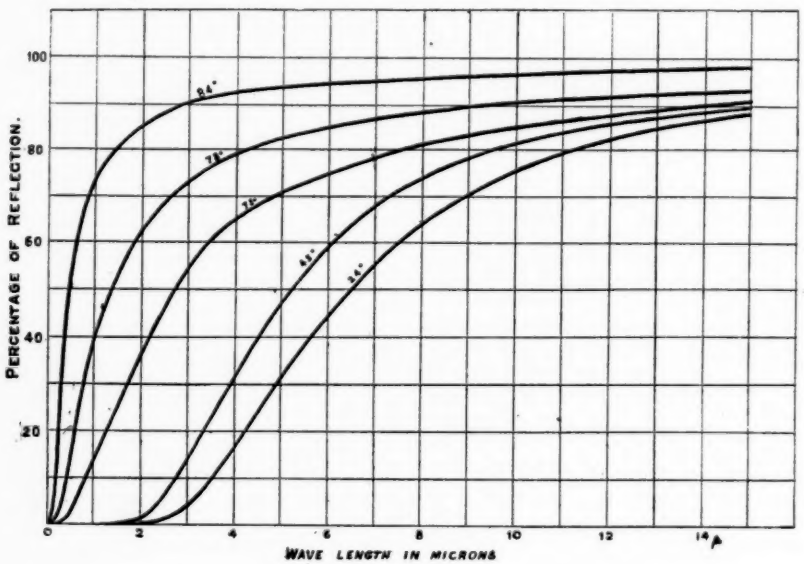

Fig. 1.

glass as compared with that of a polished surface of the same material for various angles of incidence and for various wave-lengths of incident radiation. Though the primary object of Gorton's investigation appears to have been the development of an infra-red screen, the experimental results obtained by him are also of interest from the point of view of the general theory of reflection from rough surfaces. In the present paper, it is proposed to record the results of an attempt made to develop a math-

[1] Rayleigh, Nature, 64, p. 385, 1901.

[2] T. J. Meyer, Verh. Deutsch. Phys. Ges., p. 126, Feb., 1914.

ematical formula which would quantitatively express the relative reflecting power of a rough surface over the range of incidences and wave-lengths studied by Gorton.

One important feature about the reflection from rough surfaces which is emphasized in Gorton's paper is the absence of decided interference minima in the reflection curves, such as would occur in the case of a plane grating or any surface of regular topography. This result is attributed to the fact that surfaces like those of groundglass are extremely irregular in structure. Starting on this idea, it seems possible, on certain hypotheses, to calculate the relative reflecting power of the surface for a given wave-length and a given incidence. It is convenient in the first place to make the simplifying assumption that the "relative reflecting power" of a rough surface depends only on its topography and not upon the nature of the material of which it is composed. *A priori*, it can be seen that such an assumption would not be very wide of the truth, particularly in the case of surfaces which, if polished, would have a fairly high coefficient of reflection at all incidences.[1] Further, the surface may be assumed to be "ideally rough," in other words, that different elements of it are distributed at different depths according to the probability law, the aggregate area of the elements lying between the distances x and $x + dx$ from a mean plane being proportional to $e^{-ax^2}dx$. The disturbance due to the reflected radiations is the resultant of the disturbances due to radiation from each of the surface elements, the proper phase of each being taken into account. Taking the mean plane as the reference plane, the relative phase of the disturbance sent out from an element of the surface at a depth x below it may be taken to be $2x \cos\theta \cdot 2\pi/\lambda$, where λ is the wave-length of the incident radiation, and θ the angle of incidence. Assuming now that, to a sufficient approximation, the surface is uniformly illuminated by the incident radiation, we get for the resultant disturbance due to the reflected radiation

$$y = \Sigma \cos(\omega t + 2x \cos\theta \cdot 2\pi/\lambda)ds, \qquad (1)$$

the summation extending all over the elements. Since the distribution of the elements at different depths is assumed to be according to the probability law,

$$y = \frac{\int_{-\infty}^{\infty} e^{-ax^2} \cos(\omega t + [4\pi x \cos\theta]/\lambda)dx}{\int_{-\infty}^{\infty} e^{-ax^2}dx}. \qquad (2)$$

Evaluating the integrals, the intensity of the reflected radiation is found to be given by

[1] See also Gorton's remarks, PHYS. REV., VOL. VII., ser. 2, p. 75.

$$I = e^{-(8\pi^2 \cos^2\theta)/a\lambda^2}, \qquad (3)$$

and this will also determine the relative reflecting power of the surface.

It is easily seen that this formula represents curves of the same general form as those obtained experimentally by Gorton. The curves have an inflection point, the inflectional gradient being proportional to $a^{\frac{1}{2}}/\cos\theta$, so that the curves became steeper (1) as a increases, *i. e.*, as the surface becomes finer, and (2) as the angle of incidence increases; these results are in general agreement with Gorton's observations. The actual results calculated from the formula are given below for the different surfaces used by him. The surfaces are denoted by *A*, *B*, *C*, *D*, where *A* refers to curves *I* and *II* in Fig. 6 (p. 73) of his paper, *B* refers to curve *III* in the same figure, and *C* and *D* refer respectively to the curves in Figs. 7 and 8. It will be seen from Table I. that for moderate incidences the agreement is fairly good.

TABLE I.

Surface.	Angle of Incidence.		Relative Reflecting Power (as Percentages) for Wave-lengths (in μ).										
			1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
A	23°	Obsd.	—	0.8	4.0	13.9	26.6	38.2	47.4	56.7	63.8	68.5	71.6
		Calcd.	—	0.0	2.0	10.6	23.8	36.9	47.1	57.0	64.2	69.8	74.3
B	45°	Obsd.	—	15.9	33.8	50.3	62.7	71.5	77.7	81.7	—	—	—
		Calcd.	—	7.1	30.8	51.6	65.5	74.5	80.5	84.7	—	—	—
C	24°	Obsd.	2.0	3.2	7.9	19.1	32.1	44.5	54.1	63.7	69.8	75.0	—
		Calcd.	0.0	0.0	4.1	16.6	31.6	45.0	55.6	63.8	70.1	75.0	—
	45°	Obsd.	3.2	5.3	17.3	33.2	48.0	59.0	67.1	73.1	77.4	79.5	82.3
		Calcd.	0.0	1.3	14.7	34.0	50.2	61.9	70.3	76.4	80.8	84.2	86.7
D	54°	Obsd.	—	8.2	28.0	45.6	59.5	69.9	75.2	—	—	—	—
		Calcd.	—	4.0	24.0	44.8	59.8	70.0	76.9	—	—	—	—

But at oblique incidences, the simple single-constant formula fails to express the results quantitatively, as can be seen from the figures in Table II. below.

TABLE II.

Surface.	Angle of Incidence.		Percentage of Reflection for Wave-lengths (in μ).										
			1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
A	70°	Obsd.	4.0	25.3	39.8	48.1	55.3	60.2	63.7	66.9	70.1	72.6	75.2
		Calcd.	0.7	28.9	57.5	73.1	82.0	87.1	90.4	92.5	94.1	95.1	96.0
C	72°	Obsd.	17.0	36.9	51.0	62.3	69.3	74.4	77.9	80.9	83.1	84.7	—
		Calcd.	3.7	43.9	69.4	81.4	87.6	91.3	93.5	95.0	96.0	96.7	—
	84°	Obsd.	73.3	85.7	90.4	93.3	95.1	95.9	96.5	97.0	97.5	97.8	98.1
		Calcd.	68.9	91.1	95.9	97.7	98.5	99.0	99.2	99.4	99.5	99.6	99.7
D	70°	Obsd.	11.0	46.3	66.9	77.3	83.4	85.1	85.1	—	—	—	—
		Calcd.	1.3	33.7	61.7	76.2	84.0	88.6	91.5	—	—	—	—
	81°	Obsd.	82.3	92.5	94.7	96.3	97.7	98.7	99.3	—	—	—	—
		Calcd.	41.0	80.0	90.5	94.6	96.5	97.5	98.2	—	—	—	—

The constants for the different surfaces are as follows: [1]

Surface.	*A.*	*B.*	*C.*	*D.*
$a\ 10^8 \times$	1.86	3.72	2.29	2.13
$d\ \mu$	0.61	0.43	0.55	0.56

the height above or depth below the mean plane for which the proportional frequency of occurrence is one half being given by d in the second line.

The failure of the simple theory given above to account for the phenomena observed at very oblique incidences could have been anticipated; for, the assumption made that the elements of the rough surface are all equally illuminated by the incident radiation would obviously be wide of the mark at such incidences. The extent of the discrepancy evidently depends on the degree of rugosity of the surface. If this is very marked, and the radiation is of relatively short wave-length and is incident very obliquely, hardly anything more than the upper parts of the surface would be illuminated. These would act as diffracting sources of radiation, the permanent phase differences between them being, of course, much smaller than the phase differences between the radiations from the highest and deepest parts of the surface. On the other hand, with greater wave-lengths, even the deeper parts of the surface would contribute to the reflection, but the increase due to this may to some extent be set off by the larger phase differences that come into play.[2] In view of these complications, it seems very difficult to give even an approximate theoretical treatment for the case of very oblique incidences. An empirical formula may however be devised to fit the experimental results. This should obviously satisfy the following conditions indicated by theory. (*a*) For very large wave-lengths, the relative reflecting power should be unity. (*b*) For moderate obliquities and over a range of incidences depending on the rugosity of the surface, it should reduce to the simple single-constant formula (3) above. (*c*) For very oblique incidences, it should give results, which, for short wave-lengths, should be greater, but which increase with the wave-length less rapidly than as suggested by the single-constant formula (3). In divising such a formula, preference has naturally been given to terms of the exponential type suggested by the simple theory. The formula which has been found suitable is

$$I = e^{-a \tan^3 \theta} e^{-(b \cos^2 \theta)/\lambda^2} + (1 - e^{-a \tan^3 \theta}) e^{-(c \cos \theta + d \cos^2 \theta)/\lambda}.$$

[1] The surfaces *A* and *B* had been silvered, *C* had been platinized cathodically, but *D* was unsilvered.

[2] The expression $2x \cos\theta \cdot 2\pi/\lambda$ for the phase difference between the radiations from the mean plane and a plane at a distance x from it will not, also, be valid in these circumstances.

This formula evidently satisfies the conditions stated above. For, when $\lambda = \infty$, I is unity. When θ is small, the factor $e^{-a \tan^3 \theta}$ is practically unity, and the expression reduces to the formula (3). On the other hand, when θ approaches $\pi/2$, this factor becomes negligible, and the expression reduces to the form

$$I = e^{-(c \cos\theta + d \cos^2 \theta)/\lambda}$$

which approaches unity more slowly than (3) as λ is increased. The actual results calculated from this empirical formula have been plotted out in Fig. 1 for the surface *C*. The numerical values have also been given in Table III. for detailed comparison with Gorton's observations. The constants used have the following values. It will be seen that of the four constants, a is the one most sensitive to alterations in the character of the surface.

Surface.	*A.*	*C.*	*D.*
a	0.24	0.079	0.0115
b	42.4	34.5	32.9 ($\times 10^{-8}$)
c	2.5	1.43	0.0 ($\times 10^{-4}$)
d	17.8	15.75	7.89 ($\times 10^{-4}$)

TABLE III.

Surface.	Angle of Incidence.		Percentage of Reflection for Wave-lengths (in μ).										
			1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
A	23°	Obsd.	—	0.8	4.0	13.9	26.6	38.2	47.4	56.7	63.8	68.5	71.6
		Calcd.	—	0.0	2.0	10.6	23.8	36.9	47.1	57.0	64.2	69.8	74.3
	70°	Obsd.	4.0	25.3	39.8	48.1	55.3	60.2	63.7	66.9	70.1	72.6	75.2
		Calcd.	5.3	23.0	37.5	48.0	55.6	61.3	65.7	69.2	72.1	74.5	76.5
C	24°	Obsd.	2.0	3.2	7.9	19.1	32.1	44.5	54.1	63.7	69.8	75.0	77.9
		Calcd.	0.0	0.0	4.1	16.6	31.6	44.9	55.6	63.8	70.1	75.0	78.8
	45°	Obsd.	3.2	5.3	17.3	33.2	48.0	59.0	67.0	73.1	77.4	79.5	82.3
		Calcd.	0.0	1.3	14.2	32.3	47.4	59.1	67.3	73.3	77.7	81.1	83.6
	72°	Obsd.	17.0	36.9	51.0	62.3	69.3	74.4	77.9	80.9	83.1	84.7	—
		Calcd.	14.5	36.1	55.5	64.9	71.0	75.3	78.4	80.9	82.9	84.5	—
	78°	Obsd.	38.2	55.6	64.7	70.3	73.3	76.8	79.6	81.7	83.8	85.8	87.7
		Calcd.	39.1	62.5	73.1	79.1	82.9	85.6	87.5	89.0	90.1	91.0	91.8
	84°	Obsd.	73.3	85.7	90.4	93.3	95.1	95.9	96.5	97.0	97.5	97.8	98.1
		Calcd.	73.3	85.6	90.2	92.5	94.0	95.0	95.6	96.2	96.6	97.0	97.2
D	54°	Obsd.	—	8.2	28.0	45.6	59.5	69.9	75.2	—	—	—	—
		Calcd.	—	4.5	24.0	44.5	59.5	69.6	76.3	—	—	—	—
	70°	Obsd.	11.0	46.3	66.9	77.3	83.4	85.1	85.1	—	—	—	—
		Calcd.	9.4	40.0	64.0	76.7	83.6	87.9	90.5	—	—	—	—
	75°	Obsd.	31.0	66.1	77.1	84.0	88.1	90.3	91.2	—	—	—	—
		Calcd.	32.6	66.4	80.8	87.3	90.8	92.9	94.2	—	—	—	—
	81°	Obsd.	82.3	92.5	94.7	96.3	97.7	98.7	99.3	—	—	—	—
		Calcd.	80.6	90.4	93.7	95.3	96.2	96.9	97.5	—	—	—	—

The agreement between the calculated and the observed values in Table III. seems fairly good, except in the case of Surface C for an incidence of 78° for which the corresponding experimental curve given by Gorton appears to be rather irregular. The fact that the empirical formula suggested is found to give fair agreement with observations on three different surfaces at different angles of incidence and for different wave-lengths over a wide range makes it probable that it is of fairly general application to rough surfaces.

AMPLIFICATION OF THE PHOTOELECTRIC CURRENT BY MEANS OF THE AUDION.

BY CARL ELI PIKE.

A METHOD has been outlined by Jakob Kunz[1] by means of which the photoelectric current may be amplified, thus making the photoelectric cell more useful as a photometer, especially in the region of ultra-violet light and also for technical purposes.

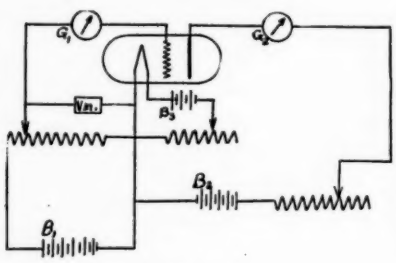

Fig. 1.

The amplification is produced by means of a vacuum tube with three electrodes, or the audion. In order to determine the best potentials to use in the primary and secondary circuits it is necessary to know the characteristic curves for the audions used. The characteristic curves of several audions have been determined by an arrangement of apparatus shown in Fig. 1, which is self explanatory. If we plot the grid potentials as abscissæ and the plate current as ordinates, the curve obtained is called the characteristic.

Due to the fact that the plate current as well as the grid current was so sensitive to small changes in the temperature of the filament, it was necessary to keep the heating current very constant. Large storage cells, well insulated from the ground, were used for this purpose. A large resistance was placed in the external circuit, so that a small variation in the resistance of the filament would not affect the current appreciably. The characteristic curves of three types of audions are shown in Figs. 3, 4 and 5. Audion no. 1 is an oscillion made by the DeForest Radio Telephone and Telegraph Co. Audion no. 2 of Fig. 4 is a W-type;

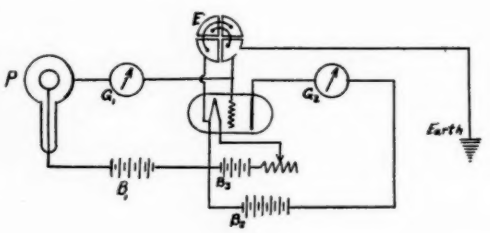

Fig. 2.

[1] PHYS. REV., Vol. X., No. 2, p. 205.

Audion no. 3 of Fig. 5 is a V-type instrument made by the Western Electric Co. It is noted that the plate current in the oscillion reaches its saturation value more abruptly than it does in either of the other two instruments. In the oscillion it is necessary to heat the filament to incandescence before the electrons are emitted, while in audion W and V the light from the filament was scarcely visible.

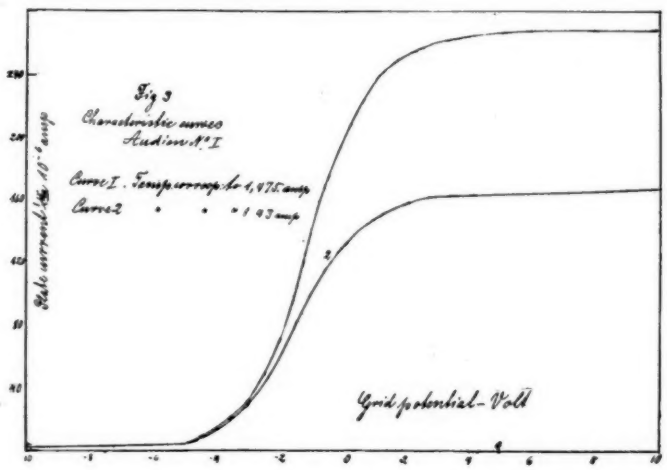

Fig. 3.

Audion no. 2, the W-type instrument, was used for the amplification of the photoelectric current, with an arrangement of apparatus shown in Fig. 2. Twenty-four volts were used in the secondary circuit and a hundred and twenty-five volts in the primary. The photoelectric cell used was a larger type of those made by Kunz in our laboratory. With 125 volts in the primary circuit, the drop of potential inside the audion was very small; measured with an electrometer it was found to be 0.56 volt for nearly the highest intensity of light incident on the photoelectric cell. Since the drop of potential between the grid and filament is very small in comparison to that across the terminals of the photoelectric cell, the photoelectric current is very nearly equal to what it would be if the audion were out of the circuit. The curve giving the relation between the intensity of light and the photoelectric current is shown in Fig. 6. It is unfortunately not a straight line. If this were a straight line and if the portion of the characteristic curve of the audion, used for the amplification, were straight, then we would expect a straight line relation between the intensity of light and the amplified current, and the amplification i_2/i_1, the ratio of the secondary to the primary current would be constant, represented by a straight line parallel to the hori-

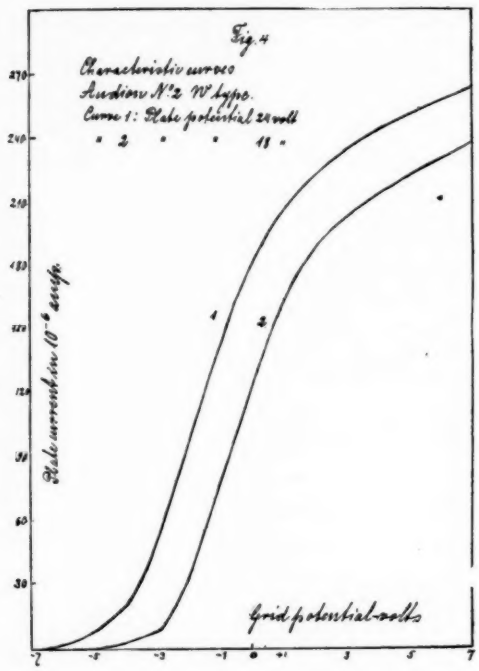
Fig. 4
Characteristic curves
Audion N°2 W type.
Curve 1: Plate potential 24 volts
" 2 " " 18 "
Plate current in 10⁻⁶ amps.
Grid potential-volts
1
2

Fig. 4.

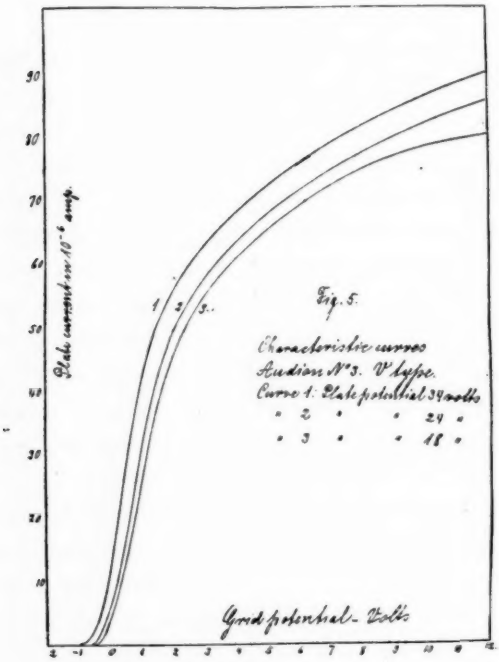
Fig. 5.
Characteristic curves
Audion N°3. V type.
Curve 1. Plate potential 30 volts
" 2 " " 24 "
" 3 " " 18 "
Plate current in 10⁻⁶ amps.
Grid potential - Volts
1
2
3

Fig. 5.

zontal axis of Fig. 7. Instead of this straight line, the curve of Fig. 7 has been obtained for intensities varying from 3 to 30 candle meters. For the highest intensity the amplification is about 1750, for the smallest

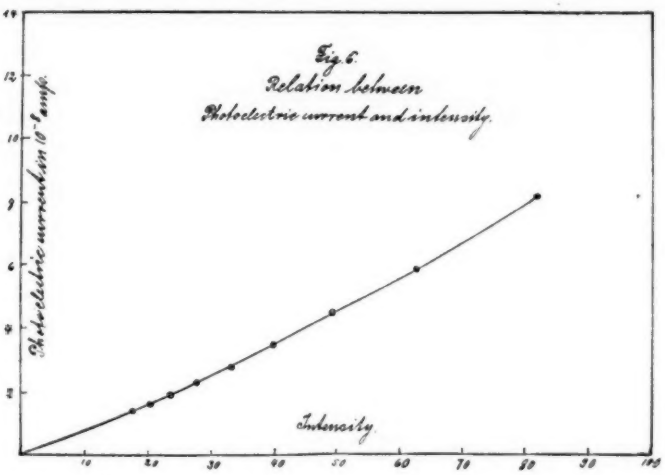

Fig. 6.

intensity it is over 5,000; above an amplification of 4,000 the points appear somewhat scattered around the curve, but this was only so because the primary current deflections of the Leeds and Northrup galvanometer,

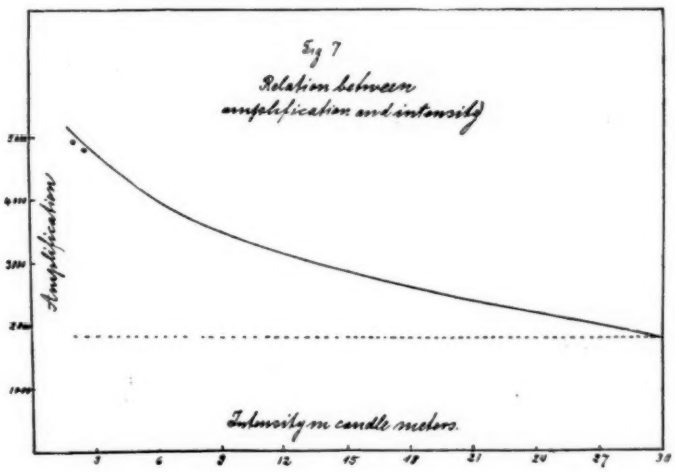

Fig. 7.

G_1 (with a figure of merit $3.74 \cdot 10^{-9}$ for the scale distance used), were very small. If the primary or photoelectric current i is zero, there is already a large current through the secondary galvanometer with a

figure of merit $2.9 \cdot 10^{-6}$. It goes without saying that this "dark" current was subtracted from that current which was obtained in the galvanometer, G_2, when the photoelectric cell was under the action of light. The difference between the two deflections was proportional to the current i_2. The deflections of the galvanometers were very steady and could easily be repeated. Table I. gives the data that have been plotted in Fig. 7. A satisfactory theory of the audion, based upon the motion, accumulation and absorption of electrons has not yet been given. The current amplification can therefore not yet be determined theoretically. But we can find a simple expression for the amplification, namely, i_2/i_1 in the following way, which involves only Ohm's law and the experimental relation between the plate current and the grid potential; as long as we restrict the amplification to the straight portion of the characteristic $i_2 = Cp_1$, we get the following equations.

$$i_1 = \frac{E_1}{R_0 + R_1} = \frac{p_1}{R_1},$$

$$i_2 = \frac{E_2}{R_2 + R_3} = \frac{p_2}{R_2} = Cp_1 = Ci_1R_1,$$

$$\frac{i_2}{i_1} = C \cdot R_1.$$

The amplification is therefore constant if C and R_1 are constants, that is, if the straight part of the characteristic is used and if the resistance R_1 between the filament and the grid is constant. For large amplifications C and R_1 have to be large.

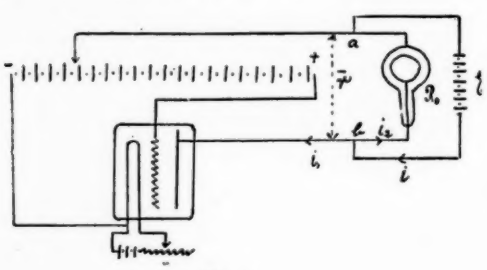

Fig. 8.

A different principle has recently been indicated by A. W. Hull,[1] of the General Electric Company, for the amplification of small currents. By a proper choice of the potentials, the electrons emitted from the incandescent filament pass through the grid and strike the plate where they are reflected. A system of this kind, shown in Fig. 8, presents a negative resistance $\bar{r}$ between the points a and b. If we place a photo-electric cell with the positive resistance R_0 in parallel with $\bar{r}$, then we get;

[1] P. I. R. E., February, 1918.

TABLE I.

Increase in d_2.	i_2 Amperes.	d_1.	i_1 Amperes.	Amplification.	Intensity in Candle Meters.
73.5	213.0×10^{-6}	35.0	131.0×10^{-9}	1600	33.0
64.8	188.0	23.5	87.7	2100	24.0
56.5	164.0	17.0	63.5	2600	18.5
49.0	142.0	12.9	48.2	2900	14.8
41.0	119.0	10.0	37.4	3270	12.0
35.5	101.5	8.1	30.2	3400	9.9
31.4	91.0	6.8	25.4	3570	8.3
28.0	81.2	5.7	21.3	3800	7.1
23.8	69.0	4.8	17.9	3840	6.1
22.5	65.2	4.1	15.3	4250	5.3
19.5	56.6	3.5	13.1	4320	4.7
17.5	50.7	3.1	11.6	4370	4.2
16.5	47.8	2.8	10.5	4570	3.7
15.1	43.7	2.5	9.4	4680	3.3
13.0	37.7	2.1	7.9	4800	3.0
12.0	34.8	1.9	7.1	4890	2.7
10.9	31.6	1.8	6.7	4720	2.5
11.5	33.3	1.7	6.4	5100	2.3
10.0	29.0	1.6	6.0	4840	2.1
10.0	29.0	1.5	5.6	5200	1.9

"W" type audion, no. 2. Lamp current, 3.75 amperes; candle power, 3.0. Heating current, 0.665 amperes. B^1 equaled 125 volts. B^2 equaled 25 volts. Figure of merit of G^1 3.74×10^{-9}. Figure of merit of G^2 2.9×10^{-6} when shunted with 1.7 ohm resistance. Ratio of figure of merit of G^2 to that of G^1 equaled 775.

$$i = i_1 + i_2 = E\left(\frac{R_0 + \bar{r}}{R\bar{r}}\right),$$

and

$$i_1 = \frac{E}{\bar{r}}, \quad i_2 = \frac{E}{R},$$

hence the amplification

$$\frac{i_2}{i} = \frac{\bar{r}}{R_0 + \bar{r}}$$

may be made very large by making r and R_0 nearly equal in absolute values.

One application of the amplification of photoelectric currents in wireless telegraphy may be pointed out. J. Kunz and J. Kemp[1] have at first used the photoelectric cell as receiver in wireless telegraphy. Their method has been modified by H. Behnken[2] who showed that the photoelectric cell with a string electrometer forms a constant detector of high sensitiveness, especially useful for photographic registrations. With

[1] Jahrbuch d. drahtlosen Telegraphie, 6, 405, 1913.

[2] Verhdlg d. deutschen phys. Ges., 16, p. 668, 1914.

the amplification of the weak currents here involved it should be possible to increase the usefulness of the photoelectric detector. It was intended to continue this investigation with ultra-violet and interrupted light, with alternating currents, and with a differential galvanometer in the secondary circuit.

SUMMARY.

It has been shown that photoelectric currents can be amplified by means of the audion from 1,600 to 5,000 times. The weaker the light the smaller the primary photoelectric current and the larger the amplification. With different audions amplifications of 18,000 have been obtained.

In conclusion the writer wishes to express his appreciation to Jakob Kunz for suggesting the problem and directing the work.

LABORATORY OF PHYSICS,
UNIVERSITY OF ILLINOIS,
October, 1918.

THE EMISSION AND ABSORPTION OF PHOTOELECTRONS BY PLATINUM AND SILVER.[1]

BY OTTO STUHLMAN, JR.

AS the result of light passing through very thin metal foil, photoelectrons will be emitted from both sides of the metal simultaneously. Since it will be necessary to distinguish between those electrons which are liberated from the side upon which the light is incident and those that come from the side from which the light emerges, we shall refer to them as "incidence" and "emergence" rays respectively.

It was hoped that some relations could be established between the atomic properties of metals and their photoelectric emissivity. Secondly to establish the magnitude of the coefficient of absorption of the electrons as a function of their speed and atomic properties of the metal in which the absorption was to take place. Finally to use the above information, if adequate, to throw some light on the structure of the atom.

All previous work by the writer and other investigators[2] who have been interested in the photoelectric properties of very thin metallic foil, or still thinner and transparent films of metal was undertaken with cathode deposited films supported by quartz.

The photoelectric currents and velocity investigations were, however, found to depend too much upon the previous history of the cathode and the potential gradient under which the cathodic deposit had been made to warrant any quantitative conclusions.

Thus in many cases, as in those investigations by the writer and K. T. Compton, both the magnitude of the current and the velocity of emission of the electrons could be altered at will, depending upon the impurities that are present through occlusion, in the cathode. The most serious difficulty, however, was found in mounting the very thin transparent films in such a way as to insure perfect electrical contact. These sources of error were so great that no quantitative conclusions could be drawn from the data at that time.

[1] Presented at the Amer. Phys. Soc. meeting, December 27, 1917.

[2] Stuhlman, Phil. Mag., 20, p. 331, 1910; 22, p. 854, 1911; PHYS. REV., 4, p. 195, 1914. Stuhlman and Compton, PHYS. REV., 2, Sept., 1913. Kleeman, Proc. Roy. Soc., 84, p. 92. 1910. Robinson, Phil. Mag., 23, p. 542, 1912; p. 115, 1913; V., 32, p. 421, 1916. Werner, Ark. Mat. Ast. Fys., 8, No. 27, p. 1, 1913. Partzsh and Hallwachs, Annalen XLI., p. 247, 1913. Compton and Ross, PHYS. REV., 9, p. 559, 1917.

In the present work it was found necessary to investigate metallic films of less than 10^{-6} cm. in thickness with a degree of accuracy much beyond that heretofore attained in the above experiments. It was necessary to provide films of extreme purity and make electrical contact with them which would exclude the errors introduced through direct contact clamping between these very thin films and their supports leading to the electrometer. Heretofore successive thicknesses of films were produced either through successive additions of metal to an initial thin film, or successive plates were covered with various thicknesses and then separately investigated. This necessitated the investigation of many films of varying thickness deposited on the assumption that a linear relation existed between time of sputtering, and thickness of metal deposited. To attain this experimental linear relation by keeping the working conditions constant enough in the cathode-depositing-chamber through control of vacuum and cathode fall is itself quite a difficult undertaking.

TRANSPARENT METALLIC WEDGES WERE DEPOSITED.

In order to obviate the necessity of examining a large number of transparent films of successive increasing thickness, or of examining one film which had been built up of successive layers which had been photoelectrically fatigued through long use, the feasibility of substituting a transparent or semi-transparent metallic wedge was considered.

The deposition of such a wedge by an electrolytic method was however rejected. The difficulties of this method of deposition may be appreciated since we learn from Kundt's[1] well-known experiments on the optical constants of metals, that out of several thousand attempts only a score of wedges were produced which were sufficiently perfect to warrant investigation. A further objection however arises. A chemically deposited metal would contain impurities through occlusion of the electrolyte with the subsequent formation of polarized electrical double layers, which may become so prominent as to prevent all electronic emission.

A metallic wedge deposited by evaporation in vacuo from a fine wire, heated to luminescence, was eventually found to meet the above requirements and objections.

The method[2] essentially consists of a wire, heated to incandescence by means of an electric current, while the quartz plate upon which the wedge is to be deposited is placed below and to one side of it. If the whole is now placed in vacuo, the metal will vaporize and condense upon the quartz surface and surrounding objects.

[1] See Kayser Handbuch der Spectroscopie, IV. Band. p. 542.

[2] Stuhlman. Presented before the Amer. Phys. Soc., New York meeting, December, 1916. Also Jour. Optical Soc. of Amer., V., 1, p. 78, 1917.

Under similar conditions Langmuir[1] has shown that the rate of evaporation m of an incandescent body is expressed by the relation

$$m = \sqrt{\frac{M}{2\pi RT}} \cdot p,$$

where M is the molecular weight of the vapor and p its vapor pressure. He has also shown that no reflection of molecules of the metal takes place at the surface upon which they initially strike, unless the surface is so hot as to cause reëvaporation. Under the above conditions we can therefore conclude that the total amount condensed per second is equal to the loss per second which the wire undergoes through evaporation.

Hence given a wire whose cross-sectional area is small compared with its distance above the plane, over which it is placed horizontally, it may be treated as a linear source which is sending out metallic vapor in all directions at right angles to its surface. Since no reflection takes place from the horizontal plane under the working conditions, then $dm/2\pi$ can represent the amount of evaporated metal passing through unit angle per second and subsequently condensed from a length dl of wire. Let the wire be stretched parallel to and at a height h cm. above the horizontal plane in which the quartz plate is placed, upon which the deposition is to form. After n seconds let t_0 represent the thickness of the metal condensed on the plane just below the wire. The flux per second of metal through an angle $d\theta$ condensing just below the wire producing this thickness t_0 is then

$$t_0 h d\theta = \frac{dm}{2\pi} d\theta.$$

The simultaneous condensation at any other point in the plane at a perpendicular distance r from the wire is given by

$$t_n ds = \frac{dm}{2\pi} d\theta.$$

Since

$$t_0 h d\theta = t_n ds = \frac{t_n r d\theta}{\cos\theta}$$

it follows that the thickness of deposit at any point in the plane is

$$t_n = \frac{t_0 h^2}{h^2 + x^2}, \qquad (1)$$

where x represents the distance of the point n from the foot of the perpendicular h let fall from the wire to the plane. If we set $h = 2a$ and $t_n = y$ the equation reduces to the well-known curve

[1] Phys. Rev., V., 2, p. 340, 1913.

$$y = \frac{8a^3}{x^2 + 4a^2}, \tag{2}$$

the "Witch of Agnesi," so that a section through the solid deposit formed from an evaporating wire, at constant temperature, with vacuum at constant pressure can be represented by the above curve. The deposit just below the wire is however not a wedge. It has a pronounced curvature concave downward, followed by a curvature concave upward. Further along, that is for the values of x ten times larger than values of y, the curve approaches a straight line. It was in this region that the quartz plate was placed, which was to receive the metal, where the deposit would approach nearest to the desired form of a true wedge.

Apparatus used to Deposit Wedges.

Fig. 1 shows a diagrammatic representation of the apparatus. Although originally[1] designed to make interferometer or opaque mirrors of uniform texture and optical purity, it was found to answer the requirements for the present purpose. The working parts are mounted on a thick plate of rolled brass, grooved to hold the bell jar *BJ*. Hard sealing wax floated in this groove formed the seal for the vacuum which was maintained by means of a Gaede rotary mercury pump. The carriage *HE* supports the incandescent wire. At *H* the wire is attached to a screw at the top of the rod connecting the two wheels, from where it passes down and then through a large hole in the rod between the wheels, then across through a similar hole in the rod at *E*, thence to the spring brass hook, *E*. This spring hook supplies the necessary tension to the wire. Upon heating the wire, it expands and the slack is further taken up by the spring in the hook. For the heating current a 110-volt alternating current was used. The quartz plate was placed in the plane *P* below and to one side of the wire.

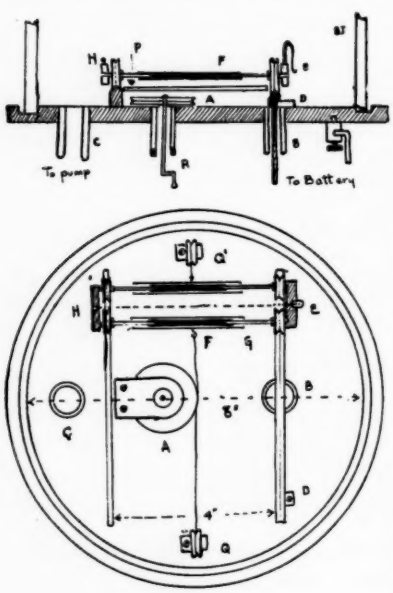

Fig. 1.

[1] Read as a paper before the Amer. Phys. Soc., New York, December, 1916. Jour. Optical Soc., V., 1, p. 78, 1917.

The heating-current enters the base plate at the binding post to the right. It then passes into the metallic track at H which is screwed to the base plate. From here it passes through the left side of the carriage, thence through the wire across to E into the right-hand track. This track is insulated from the base-plate by means of two fiber L-shaped supports. The current passes from this insulated track through the rod B back to the battery. The rod B passes through a hole in the base-plate and is sealed in place with hard red sealing wax, which serves to insulate it from the plate and at the same time makes the opening air tight.

To prevent the carriage supports from short circuiting the glowing wire, they are separated by hard fiber rods. This joint F was then covered with a tight-fitting glass tube extending one centimeter beyond each end of the fiber insulation. This prevented the fiber from being coated with a metallic deposit which would otherwise short circuit the glowing wire. In order to shift the carriage it was necessary to have a mechanical control outside of the apparatus. (A magnetic control would be simpler for the present purpose.) It was supplied by means of a small crank which passed through a ground glass stopper sealed in the tube at R. This crank turned the horizontal V-grooved wheel A, around which passed a belt to the small wheel Q, from where it passed to a hook on the carriage at F. The other end of the belt passed over a similar wheel at Q' and thence to a similar hook on the other side of the carriage. By turning the crank R, the carriage and wire could be rolled to any position above the plane P which contained the quartz plate upon which the metallic wedge is deposited.

In order to insure a very pure deposit it was found necessary to acid clean the wire thoroughly. It was then mounted and heated in vacuo, but not so high as to produce evaporation. This removed most of the occluded gases and such impurities which would otherwise have been condensed on the quartz plate. The wire is now set at the proper distance from the quartz plate and allowed to vaporize until the desired thickness of metal has been attained.

A metallic deposit condensed as outlined above, was first examined for change in thickness as the distance from the wire increased; with a view of ascertaining how near photometric measurements could determine changes in thickness. A glass microscope slide 10×1 cm. was placed directly beneath and 1 cm. below the wire and the metal was deposited until the region just below the wire was opaque. The deposit was next examined by means of a microphotometer with unresolved light from a tungsten filament lamp. A beam 1×10 mm. was directed normally on

the metallic side and after passing through the wedge was focussed on a linear thermopile in vacuo. The throw of a ballistic galvanometer in series was used to measure the current, which was assumed to indicate, in a rough way, the change in thickness of the wedge as successive millimeter portions were passed before the slit of the thermopile.[1] No quantitative conclusions were expected from these data due to the change in the optical constants with change in thickness of the film.

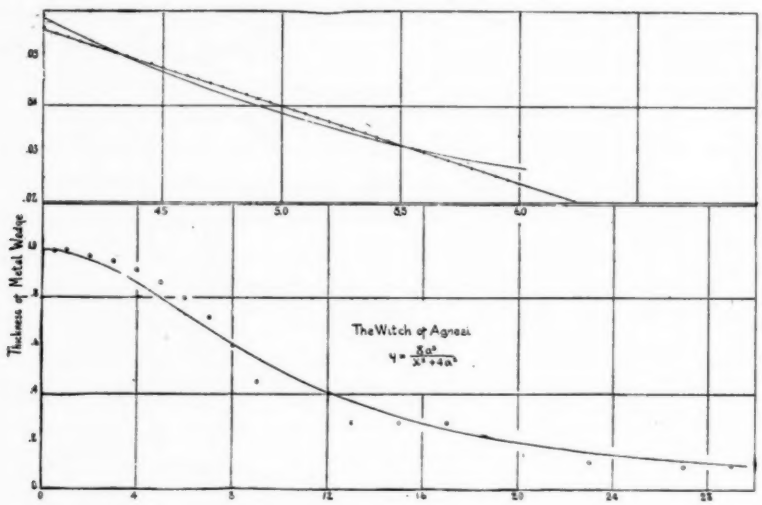

Fig. 2.

These more or less approximate results are shown in the lower curve of Fig. 2. The agreement between the observations as recorded and the theoretical equation $y = 8a^3/(x^2 + 4a^2)$ plotted, as a full line, are as close as might be expected under the circumstances.

In order to determine how near to the wire the best approach to a true wedge could be expected, the following graphical method was resorted to. The theoretical curve was plotted on large scale coördinate paper and that part of the curve chosen which fitted nearest to a straight line within an average of five per cent. The upper graph in Fig. 2 shows the portion of the curve chosen. The solid line represents values computed from the theoretical equation, for the thick end of the wedge at a distance of four centimeters from the foot of the normal let fall from the wire to the plane. The broken graph is a straight line drawn through the average value of the points. Although the metal deposited at this distance from the wire has a slightly concave surface, yet it approaches a straight

[1] I am indebted to Dr. Ives, of the United Gas Improvement Co., Philadelphia, for the use of this apparatus, and to Dr. Eckhardt for assistance with these observations.

line wedge with not more than a maximum of five per cent. variation at any point. This five per cent. error, contributed by the straight line assumption, is within the error of observation contributed by the subsequent photoelectric current measurements.

The metallic wedges investigated in this paper were all deposited in this region.

The Wedges.

The metals investigated were platinum and silver. They were deposited from chemically pure wires .043 cm. in diameter. The wire was 12 cm. above the plane which contained a 2.5 × 1.0 × 0.1 cm. quartz plate placed four centimeters away from, with its narrow side parallel to, the incandescent wire.

The platinum wedges, when examined by reflected light, showed for the opaque deposit at the edge nearest to the glowing wire, the characteristic metallic lustre of the metal. Semi-opaque thicknesses transmitted red light and reflected blue. As the thickness decreased the reflected light changed from blue to brown, to yellow, to blue and at the very thinnest end to indigo. The colors of the transmitted light for the same thicknesses were gray brown, greenish blue and reddish brown.

Silver wedges which were opaque at one end and shaded to zero thickness at the other end in 4 cm. of length showed the following variation in color. Deep violet was transmitted through the nearly opaque thicker end, shading into violet, blue, light blue, deep blue, purple, red, brown and into yellow at its thinnest end. The corresponding points when viewed by reflected light showed at the opaque end the metallic luster of silver followed by deep green, green, green blue, red green, red, blue red, blue and a lighter blue at its thinnest end.

An absorption band might hence be expected to exist in the green part of the spectrum about λ 4500. An absorption spectrum photograph obtained by means of a Hilger monochromatic illuminator through one of the silver wedges, showed a continuous gradually increasing absorption through the red and yellow, terminating at about λ 5300, from here a weak broad green blue absorption band exists terminating at about λ 4000 from where the absorption again drops off regularly into the violet but at a greater rate than the ascent in the red end.

While the thick and nearly opaque ends of some of the platinum wedges are transparent to red light (in fact the glowing filament of a tungsten lamp was visible through the thick end as a brilliant red image); the thick or nearly opaque end of the silver wedge showed the same filament as an indigo-blue image. Showing that the shorter wave-lengths penetrate further into a silver surface than into platinum. What evidence the

photoelectric observations throw on this topic will be discussed in a separate chapter.

THE ARRANGEMENT OF THE APPARATUS.

The metallic wedge (1 × 2.5 cm.) supported by the quartz plate is shown in Fig. 3 as *Q*. It was mounted with the thick end of the wedge attached to the brass holder *E*. A countersunk screw pressed the metal-covered side of the quartz plate rigidly against the opposite facet of the clamp at *E*. This clamp was screwed to a rod ending in a rack *B*, which slid under V-shaped grooves in the fixture *A*. The pinion *N* engaging the rack, pushed the wedge into any desired position with respect to the beam of light *T* which was used to excite the photoelectric phenomena. The position with respect to the illumination was indicated on the steel millimeter scale *S* fastened to the fixture at *A*. This motion of the wedge allowed one to expose successively increasing or decreasing thickness of the metal to the beam of ultra-violet monochromatic illumination passing through a Hilger Monochromatic Illuminator placed in front of the slit *R*. A 110-volt Cooper Hewitt quartz mercury arc running under constant power supplied the illumination. The slit at *R* was so adjusted that a clear cut image 8 mm. long and 0.23 mm. wide fell on the quartz plate at *T*. The degree of sharpness of the image and its position was at all times controlled by means of a fluorescent plate which could be substituted for *Q* and by means of a fluoroscope eye piece placed at *O*. The photoelectric chamber *D* is an oxidized copper cylinder covered with camphor soot whose photoelectric constants were well known, having been repeatedly used in former experiments. This cylinder D was mounted coaxially with the outer brass casing *P*. It was connected as shown, to an electrometer after passing through the hard sealing wax support at *P*. The electrometer showed a consistent sensibility of 1,220 divisions per volt which did not vary more than 1.3 per cent. during the course of the experiments.

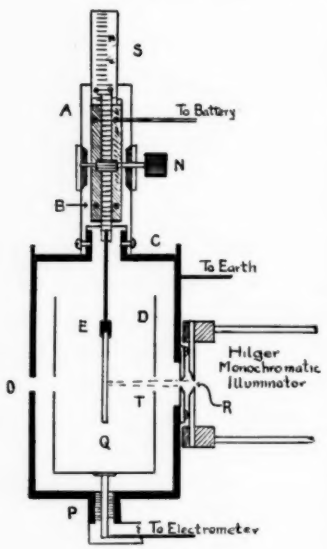

Fig. 3.

The present method differs fundamentally from previous measurements on thin metal films in so far as photoelectric current can be mea-

sured from one film, possessing various thicknesses and having the same history of production and ageing. An additional improvement consists in being able to examine the very thinnest film without introducing special appliances or precautions for electrical contact. It also allows one to measure the thickness of the very thin films to a greater degree of accuracy through extrapolation from the thicker films, which in turn lend themselves more easily to accurate measurements.

The wedge was exposed at millimeter intervals through its entire length. The present paper deals with the photoelectric current obtained from such a wedge when the metal side faced away from the light. Under these conditions the illumination was allowed to fall under normal incidence on the quartz side of the plate, it then passed through the transition layer quartz-metal and liberated photoelectrons in the metal. The electrons leaving the metal under these conditions are classified as "emergence." To measure the "incidence" effect all that was necessary was to rotate the superstructure in the groove *C* through 180° and repeat the measurements for thicknesses as relatively determined by the scale *S*.

FILM THICKNESS.

The determination of the thickness of the film contributed the largest error to the final results. Optical methods as developed by Wiener[1] were given up as too unreliable. A very promising method, though not used on the data presented below, and especially adaptable to silver films, is that in which the silver film is locally converted into silver iodide by means of the proximity of a minute piece of iodine. A convex lens placed upon the resulting hump allows one to use the Newtonian ring interference method for computing the thickness of the hump and from it a value of the thickness of the original silver.

Here either mechanical or electrical methods were resorted to. As in the case of platinum, when the specific resistance of the material is known in terms of thickness,[2] it was found feasible to determine the thickness at several points along the wedge by using the following indirect method.

A quartz plate, similar in size to the one upon which a wedge was deposited, was covered with a uniform film, of thickness comparable to the thick end of the wedges. This uniform film can be deposited in the apparatus discussed above by simply moving the carriage, supporting the incandescent wire, back and forth across the plate with uniform speed. After attaining its equilibrium value the film was examined for its spe-

[1] Wied. Annalen, V., 31, p. 629, 1887.

[2] Patterson, Phil. Mag., IV., p. 663, 1902. Longden, PHYS. REV., II., p. 40, 1900. I. Stone, PHYS. REV., VI., p. 1, 1898.

cific resistance. This resistance data could be used to compute its thickness. A photoelectric examination of this uniform surface made under similar conditions as existed when the wedge was investigated, determined the thickness of that part of the wedge which showed an equal photoelectric current.

When the thickness of the plane film was large enough, the above method was checked by direct weighing. The plane silver films could be changed to the iodide form, and then weighed, and from these results the thickness can be computed.[1]

EMERGENCE PHOTOELECTRIC CURRENT OBSERVATIONS.

The photoelectric currents for wave-lengths 2260, 2301, 2536 and 3131 were obtained for platinum and silver with variations in thickness of the metal exposed. Since the various spectral lines are not of equal

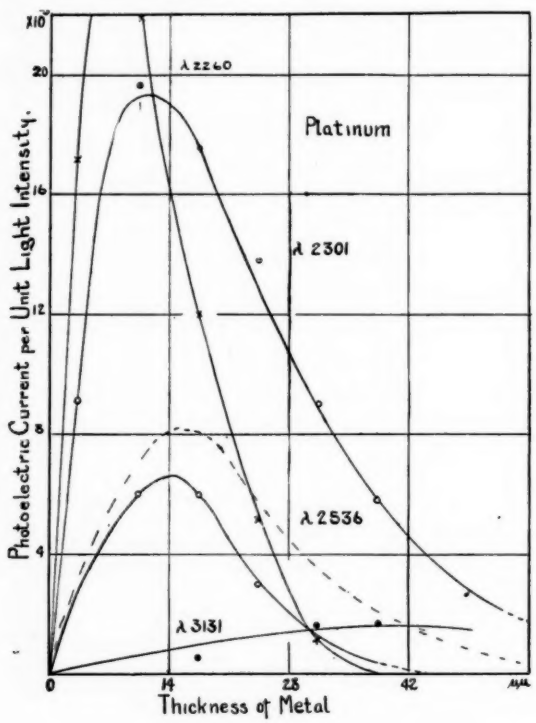

Fig. 4.

intensity the observations were reduced to represent current per unit incident light intensity, by dividing the number of electrons liberated per unit time by the energy of the light of the corresponding wave-length.

[1] Quinicke, Pogg. Ann., 129, p. 178, 186 .

The ordinates thus plotted in subsequent curves represent the relative number of electrons liberated in unit time by a unit amount of light-energy for the wave-length indicated.

In the case of platinum an attempt was made to get some results from λ 3131 but with little success, since platinum is no longer photoelectric sensitive for this wave-length. These latter results are only introduced for qualitative comparison, and since no light filter was used, no doubt the observed current was not really due to the excitation from this wave length, but from a somewhat shorter wave-length.

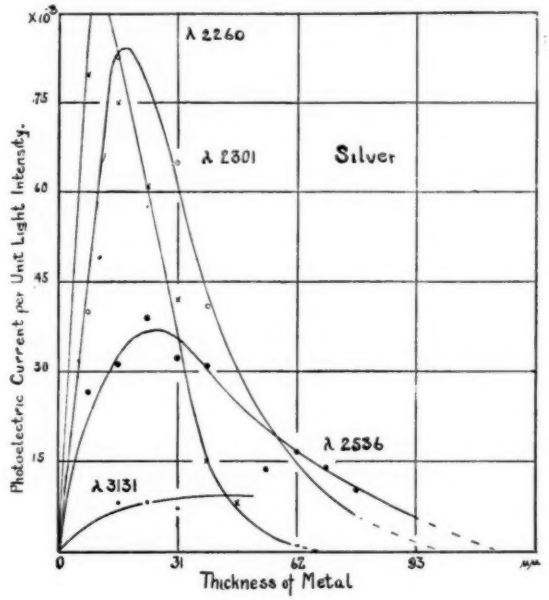

Fig. 5.

Figs. 4 and 5 show a typical set of observations for each of the metals. To avoid the error that might be introduced by photoelectric fatigue it was found necessary to prepare a separate wedge of metal for the observations obtained for each wave-length examined.

The photoelectric observations could be duplicated with a mean error of five per cent., but since the thickness determinations possessed an average error of ten per cent., no additional precautions were introduced into the photoelectric measurements to insure a greater accuracy. The constants computed from these curves show a degree of consistency in agreement with the above errors, which serve as a good check on the observational values.

In Fig. 4 the dotted line for λ 2536 gives the unfatigued values of the

photoelectric current computed from the solid fatigued curve just below it. The ordinates of this curve were obtained by increasing the observed fatigued values by an amount experimentally determinable and proportional to the time elapsing between the removal of the wedge from its vacuum chamber and its subsequent photoelectric examination.

The curves for both metals have this in common; all make finite angles with the abscissa. There is no sign of inflexion on the ascent of the curve, so that the tangent to the curve at the origin is more inclined to the abscissa than the tangent at any other point. This means that for the very thinnest part of the wedge (atomic thickness) the photoelectric effect occurring there for any frequency of the exciting light, bears a definite ratio to the mass per square centimeter of the film. The slopes of the curves at the origin are relative measures of the energy absorbed by a film thickness comparable to the diameter of one molecule.

The curves can, for the sake of discussion, be divided into two parts. The initial rise which appears to be a type of saturation curve, and superimposed upon this a second phenomena of a more complex nature approximately represented by an exponential drop followed by a linear relation ending in another less rapid fall.

These two phenomena will be treated separately under the subject of scattering and absorption of photoelectrons.

The photoelectric current is excited by a monochromatic beam of light falling normally on the metal surface, and if no electronic absorption takes place the photoelectric current should be proportional to the light energy absorbed. If the optical constants of the metal do not change with change in film thickness for the wave-lengths used, it would follow that as the thickness of the metal increases linearly the photoelectric current should increase exponentially. This would continue until a thickness is attained beyond which the monochromatic light could no longer penetrate. This does not however hold true. When we measure the emergence effect, the curves seem to indicate that the light gives rise to electrons in amount apparently greater than the amount of light absorbed. It becomes therefore necessary to determine the cause of this additional electronic activity.

THEORY.

For the sake of simplicity let us consider only those electrons which leave the atom in the emergence direction, possessing energy proportional to the frequencè of the exciting light but independent of the kind of atom from which they initially escape.

As the liberated electrons pass through successive layers of matter,

let us further assume for simplicity that they are absorbed according to an exponential law.

If then a beam of light of frequency ν strikes a metal film, and if I_0 is the intensity penetrating the surface normally, if the intensity has fallen to I after passing through a thickness dx, then

$$I = I_0 e^{-\epsilon x}.$$

If all of the absorbed energy is used in liberating photoelectrons in such a way that the energy absorbed is equal to the photoelectric energy liberated then

$$I_0 - I = I_0(1 - e^{-\epsilon x}), \tag{3}$$

where ϵ is a constant, denoting the rate of appearance of electrons. It depends on the frequency of the light used and may be identified with the coefficient of absorption of the light. Since electronic density and light intensity are proportional under these circumstances, I_0 can be considered a variable, subsequently to be absorbed exponentially in the distance $t - x$. Then

$$\frac{dI_0}{dx} = -\alpha I_0$$

where α is the coefficient of absorption of the electrons passing through thickness $t - x$. The solution of this relation is given by

$$I_o = I' e^{-\alpha(t-x)}.$$

Since all the electrons due to any frequency ν of the light have the same initial velocity and hence may initially be considered a homogeneous beam coming from a layer of metal between x and $x + dx$, it follows if we assume that only those electrons are considered that move off in the emergence direction, that the intensity of the emergence radiation is proportional to

$$\frac{dN}{dx} = \epsilon I_0 e^{-\epsilon x} = \epsilon I' \int_0^t e^{-\epsilon x} e^{-\alpha(t-x)} dx$$

and

$$N = \frac{\epsilon I'}{\alpha - \epsilon}(e^{-\epsilon t} - e^{-\alpha t}). \tag{4}$$

It is seen that for small thicknesses the photoelectric current is proportional to the thickness or number of atoms per cubic centimeter. With increased thickness the curve passes through a maximum when

$$t_m = \frac{1}{\alpha - \epsilon} \log_e \frac{\alpha}{\epsilon} \tag{5}$$

and apparently decreases exponentially with the intensity $I' e^{-\epsilon t}$.

In order to determine to what extent the above curves check this theory the discussion is for convenience divided into two parts, the initial absorption of light as a function of the thickness and the absorption of the photoelectrons as determined by that part of the curve showing the decrease of the photoelectric effect with its subsequent disappearance as the thickness increases.

ABSORPTION OF LIGHT WITH VARIATION IN THICKNESS.

If under the experimental conditions outlined above, the photoelectric current is represented for any thickness t, by the relation $I_0(1 - e^{-\epsilon t})$ then this is equivalent to saying that the intensity of the electronic radiation from a unit area of the metal is always proportional to the number

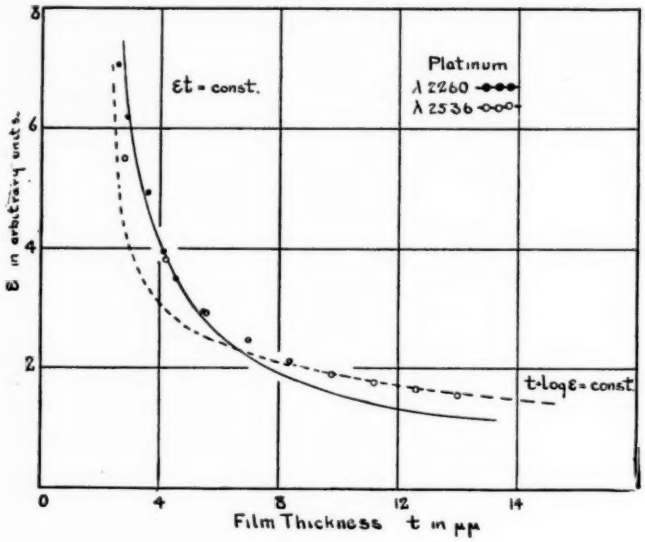

Fig. 6.

of atoms present in one cubic centimeter. The values of ϵ therefore obtained from these curves would help to determine the validity of this relation. If the number of electrons liberated are proportional to the amount of light absorbed, and if the metal film is so thin that the absorption of the electrons as they pass through the successive layers of molecules can be neglected, then successive similar layers of the metal will absorb equal fractions of the amount of light energy they receive, provided no scattering takes place, and emit a quantity of electronic energy which is a measure of the light energy absorbed. Under these conditions we can measure the electronic energy and use it as a measure of the light energy absorbed. If then we let ϵ represent this coefficient as measured

by the electronic results, I_0 the intensity of the energy entering the slab of material, I the intensity leaving, then $I = I_0 e^{-\epsilon t}$ where t is the thickness of the slab. This may be rewritten in the form

$$\epsilon = \frac{2.3}{t} \log \frac{I_0}{I}$$

If now $\log I_0/I$ is plotted against t, the graph should be a straight line (for ϵ constant) and ϵ may be determined from the relation $\epsilon = 2.3 \times$ slope.

The curves thus obtained were however not linear, they showed a continuous decrease in the coefficient ϵ (Fig. 6) as the thickness increased. The coefficients were then computed from the photoelectric curves using the relation $\epsilon = 0.693/D$ where $e^{-0.693} = 0.5$ and D is the thickness which reduces the radiation to half value. Here $1/\epsilon$ represents the distance to which the energy penetrates before its intensity is reduced $1/e$ of its original value.

TABLE I.

Platinum, λ2301.			Silver, λ2301.		
t.	ϵ.	ϵt.	t.	ϵ.	ϵt.
1.40 μμ	.990 μμ^{-1}	1.39	1.70 μμ	.393 μμ^{-1}	.668
2.10	.660	1.39	2.54	.260	.660
2.70	.520	1.40	3.30	.206	.679
3.50	.396	1.38	4.25	.160	.680
4.20	.330	1.39	5.00	.135	.665
5.05	.283	1.43	5.77	.114	.657
5.90	.230	1.35	6.90	.100	.690

TABLE II.

Platinum, λ 2536.

t.	ϵ.	ϵt.	$t \log \epsilon$.
2.8 μμ	.550 μμ^{-1}	.154	264
4.2	.381	.160	244
5.6	.291	.163	260
7.0	.247	.173	275
8.4	.211	.177	273
9.8	.190	.186	273
11.2	.176	.197	276
12.6	.165	.208	273
14.0	.157	.216	271

The above extended values give some idea of the general trend of the results. From the samples cited in Table I. it is seen how very close the product ϵt approaches a constant for small values of thickness. The

constancy of this product was found to hold, in the case of both platinum and silver for λ 2260 and 2301, so long as the values thus obtained remained associated with very small values of t. When the thickness became larger ϵt no longer remained constant but increased with increasing values of t. A characteristic set of observations illustrating this condition is cited in Table II. If however, the relation $t \log \epsilon$ is computed from the data it is found that this relation is constant for large values but not for small values of t. As an example the case of Pt λ 2536 is cited, the change taking place at thickness 7 $\mu\mu$.

One characteristic common to all these results is that ϵt seems constant under two circumstances, either for quite a range in values of t for large values of electronic velocities, excited by means of λ 2260 or 2301, or for a very short range in the values of t (about 7 $\mu\mu$) when slower electronic velocities are used, as for example those excited by λ 2536 or 3131. Although the curve for platinum λ 3131 is shown in Fig. 4, yet the coefficients calculated from this curve were omitted owing to insufficient points on the curve to determine its initial slope. In addition the minimum wave-length sensibility for platinum is just inside the wave-length used so that the above curve must have been obtained through part of the shorter wave-lengths in the spectrum overlapping this region. The value for silver λ 3131 has only been introduced to show the order of magnitude of the value ϵt.

TABLE III.

Mean Values of ϵt = *const. for small values of* t.

λ.	*Pt.*	*Ag.*	Ratio.
2260	1.41	.681	2.07
2301	1.39	.671	2.07
2536	1.61	.983	1.64
3131		1.80	
Atomic weights	195.2	107.9	1.82

A summary of these results for values of t small, representing mean values similar to the extended data given above are shown in Table III. The last column gives the ratio of the values for this relation. It is of the same order of magnitude as the ratio of the atomic weights. We might conclude that the light energy absorbed per atom, is proportional to its atomic weight.

Before going into the possible origin of the above relations it may be of interest to examine the constancy of the relation ϵt further. The values of t were therefore plotted against values of $1/\epsilon$ (Fig. 7). Under these conditions one would expect to get a straight line whose slope would

give a relative measure of the absorption of the light in passing through a molecular layer.

Since the amount of light energy absorbed is proportional to the photoelectric energy liberated it follows that the values of ϵ determined for changes in thickness, are also measurements of the photoelectric characteristics. Under these conditions we may view the electron as liberated from its parent atom, passing through successive layers of molecules being deflected through collision with them but never entering the system of the atom to disappear through absorption.

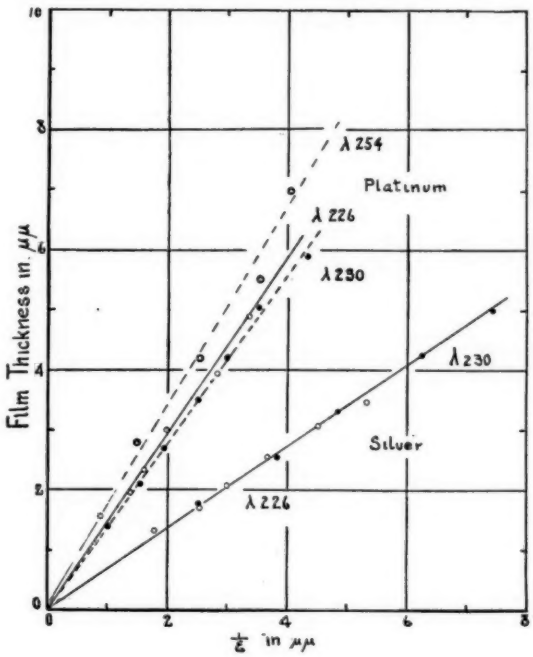

Fig. 7.

If therefore we consider two electrons, liberated with the same initial velocity, in the two metals, we will find after having passed through equal thicknesses of metal that the electron must have undergone a greater energy change per unit distance in passing through platinum than through silver. This ratio is, within experimental error, the same as the ratio of the densities of the two metals. This means that if equal masses are compared the amount of energy scattered is the same in the two cases. A similar relation exists for secondary radiation produced by Röntgen rays.[1] The above results are shown graphically in Fig. 7. In general they also seem to indicate that the greater the velocity of separation of

[1] Barkla, Phil. Mag., 7, p. 543, 1904.

the electron from its parent atom, the less the scattering of its energy as it passes through neighboring atoms. The observations for platinum λ 226 do not fall in line with this conclusion. This exception can however be attributed to experimental error. The results for Ag λ 254 are here omitted so as to prevent too much crowding in the figure. The results for λ 226 and 230 lie so close together that it is impossible to separate them in the graph, though the actual results from which the curve is compiled show that λ 230 lies to the left of the results for the smaller wave-length.

If ϵ represents the fraction of the total light energy lost through absorption and reappearing as electronic energy, in going through a sheet of metal of molecular thickness t, I_0 the intensity of the beam entering the sheet and I the intensity of the beam leaving it, then $1/\epsilon$ the intensity coming out of the sheet is given by

$$\frac{I_0 - I}{I_0} = \frac{1}{\epsilon} = kt, \tag{6}$$

where k is a constant. From which we get

$$I = I_0(1 - kt). \tag{7}$$

For larger values of t under the same circumstances it was found experimentally that

$$t \log \epsilon = \text{const.},$$

then

$$\frac{I_0 - I}{I_0} = \frac{1}{\epsilon} = e^{-c/t}, \tag{8}$$

or

$$I = I_0(1 - e^{-c/t}). \tag{9}$$

These relations do not however conform to our simple theory advanced at the beginning of the paper which involved the assumption of an exponential absorption leading to equation (4).

THEORY OF SINGLE AND COMPOUND SCATTERING.

Rutherford[1] has advanced a theory of single scattering which leads to the conclusion that the proportion I/I_0 of the rays which remain undeflected after passing through a thickness t, when t is small enough,[2] is given by the relation

$$I = I_0(1 - kt).$$

A relation deduced from the above experimental data for thicknesses less than 7 $\mu\mu$ (Fig. 6).

[1] Rutherford, Phil. Mag., V., 21, p. 684, 1911.

[2] Richardson, Electron Theory, p. 496.

For very small thicknesses we must therefore have electrons passing through the metal film, colliding according to Rutherford's hypothesis of "single scattering" and little or no energy is contributed to the atom through which the electrons passed. From this it is seen that the relation between I/I_0 and t should be nearly linear in the initial stage, and this is found to be the case for all wave-lengths for both metals investigated.

If however the thickness penetrated by the electrons becomes greater a larger number of collisions necessarily results, and then the relation $t \log \epsilon = \text{const}$ expresses the state of affairs. It seems as if the electron might be considered as at first moving in fairly straight lines with little deflection and little or no energy exchange, but as the penetration increases the deflexions become more numerous and violent resulting in the rate of expenditure of energy increasing so rapidly that the electron seems to come to a sudden stop.

This stage of the process seems to be equivalent to what Thomson[1] describes as "compound scattering." He showed that the probability of an average deflexion of an electron on passing through a metal sheet of thickness t, if less than a given angle, is equal to $1 - e^{-c/t}$ where c is a constant for any particular substance, which under the present experimental circumstances means that the proportion I/I_0 of the electrons undeflected is given by $I = I_0(1 - e^{-c/t})$ a relation identical with the empirical equation (9).

The experimental arrangement and method therefore appears to fulfill the requirements for single scattering when the metal films are very thin (less than 7 μu), and compound scattering when the metallic film is thicker (Fig. 6).

In these experiments the angular opening ϕ through which the electrons escape from the film is not varied, and if the same metal be examined so that the absorbing medium is also kept the same and the velocity of the electrons varied through change in wave-length of the illumination both Rutherford's and Thomson's theory leads to the relation,

$$\frac{mv^2}{t_0^{1/2}} = \text{const.}, \qquad (10)$$

where t_0 is the value of the thickness required to cut down the radiation to half value.

This relation can be tested with film thicknesses in which single scattering takes place. In the experimental arrangement ϕ is kept constant. Now the maximum energy of release of the electron is independent of the kind of atom and only depends on the frequency of the exciting light.

[1] Camb. Phil. Proc., 15, p. 465, 1910. See Richardson, Electron Theory, p. 493.

If therefore we consider values of $1/\epsilon$ for equal values of t_o and λ in the two metals, we have a measure of the relative average energies with which the electrons appear after passing through equal thicknesses. This also gives us a comparison of the distances to which electrons penetrate so as to have their initial energies reduced to $1/e$ of their original value. The results obtained from the data as shown in Fig. 7 indicate that equation (10) is valid within experimental error for film thickness less than 10^{-7} cm.

An interesting and rather important change takes place after the electron penetrates further into the metal. In Fig. 6, we see an illustration of the thickness at which this occurs. We are here confronted with another illustration of the sudden change in the property of a metal when its thickness is less than 10^{-7} cm. Similar changes occur in the optical and electrical properties of these metal films in this immediate vicinity.[1]

Unfortunately not enough data were available from individual results for λ 2536, to show clearly that the smaller values of t followed the ϵt = const. relation (Fig. 6), so that the values for λ 2260 were added to show how close the results fitted the theoretical curves, here shown as solid and broken lines. The latter results were therefore shifted so that the axes of the curve coincided with the axes of the curve for values λ 2536. In this way the results show graphically just where the region of separation exists to which the above theories apply.

If we now consider thicknesses in which compound shattering exists we are limited on one side by the thickness comparable to 7×10^{-7} cm. and the maxima of the curves shown in Figs. 4 and 5. As seen from the sample data shown in Table II. the coefficient decreases less rapidly than the increase in thickness. This is to be expected, if the above theory can be applied; for the amount of scattering becomes more marked with decrease in speed and increase in thickness. This continues until a critical thickness is reached where the absorption of the number of electrons becomes predominant, finally leading to a decrease in the amount of emergence radiation.

The initial rise in the curves can therefore be divided into two distinct regions. For thicknesses less than 10^{-7} cm. the velocities of the emergence electrons must be nearly equal or so nearly that very few if any electrons appear whose energy is less than that demanded by the Einstein relation. Here little if any absorption takes place so that the electron passes through subsequent layers with slight loss of energy. From here on however the number of electrons possessing less than this maximum energy decreases, they undergo frequent and violent collision

[1] Patterson, Phil. Mag., IV., p. 663, 1902. Minor, Ann. d. Phys., 10, p. 581, 1903.

with a rapid loss in energy until some electrons seem to come to a sudden stop. Further penetration is then accompanied by loss in numbers in addition to loss in energy.

Absorption of Photoelectrons.

Our theory as outlined at the beginning of the paper indicated a maximum for values of t given by the relation

$$t_m = \frac{1}{\alpha - \epsilon} \log_e \frac{\alpha}{\epsilon}.$$

The values for t_m as picked off of the ionization curves are given in Table IV., Fig. 8. The values of t_m there indicated represent the distances to

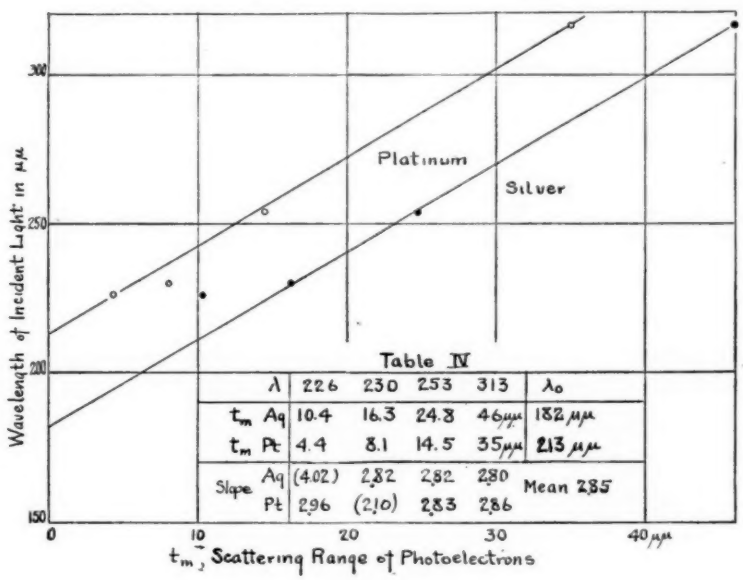

Table IV

		λ	226	230	253	313	λ_0
t_m	Ag		10.4	16.3	24.8	46 μμ	182 μμ
t_m	Pt		4.4	8.1	14.5	35 μμ	213 μμ
Slope	Ag		(4.02)	2.82	2.82	2.80	Mean 2.85
	Pt		2.96	(2.10)	2.83	2.86	

Fig. 8.

which an electron, starting from the lowest layer with initial energy $\frac{1}{2}mv^2 = h\nu$, can penetrate, before it disappears through absorption. The distance t_m is here called the scattering range. It does not measure the actual distance pursued by an electron in the form of the summation of all the zigzag paths, but the distance perpendicular to the surface of the metal. The values obtained in this way are plotted as a function of the wave-length of light causing the separation of the electron from its parent atom. The slope of the curve is the same for the two metals, the bracketed values in the table are however marked exceptions to this rule. The cause for this unusual difference cannot be accounted for through

experimental error. It seems likely however that the straight line relation is perhaps a first approximation to the truth and more numerous data determined for longer and shorter wave-lengths than here investigated will determine to a more exact degree the necessary relations.

The present curves however fit the relation $\lambda - \lambda_0 = at_m$ to a marked degree. Here a is the slope of the curve and equal to 2.85, λ_0 is the value of the minimum wave-length producing electrons possessing an effective

TABLE V.

λ in $\mu\mu$.	Velocity $\times 10^{-7}$ Cm. per Sec.				Mean Velocity.	λ_0.
	226.	230.	253.	313.		
Silver.....	14.5	14.0	13.3	13.5	13.8×10^7	182 $\mu\mu$
Platinum.....	14.1	13.8	13.2	13.4(?)	13.6×10^7	213 $\mu\mu$
$v = \sqrt{\frac{2h\nu}{m}}$.....	14.05	13.95	13.25	11.92	$\times 10^7$ cm/sec	

scattering range equal to zero. This would mean that λ_0 would be the minimum wave-length limit which could produce a photoelectric current under the above experimental conditions. Higher frequences might liberate electrons, but their energies would be so great that they could penetrate the next atoms in their path and completely disappear in their system. These electrons would be absorbed so promptly that we could expect a metal to possess the property of selective absorption for electrons possessing these critical velocities. The minimum wave-lengths of the incident light energy producing electrons under these conditions are 213 and 182 $\mu\mu$ for platinum and silver respectively.

If however the above wave-length relation is reduced to its equivalent energy form we have

$$\frac{1}{v^2} - \frac{1}{v_0^2} = bt_m, \tag{11}$$

where $b = 1.42m/hc$, assuming the relation $\frac{1}{2}mv^2 = h\nu$ to hold in the above case. We define m as the mass of the electron h as Planck's element of action and c as the velocity of light. Under these conditions v would be the velocity the electron must possess, to be able to penetrate a thickness t_m. Table V. shows the initial velocities the electrons should have, to penetrate thickness t_m, as computed from equation (11) and the velocities computed from the Einstein photoelectric equation. The contact difference of potential is here assumed equal to zero, since t_m is defined as the distance the electron travels in the metal without passing through the contact difference of potential layer. This use of the value

of t_m is however not rigidly true but owing to lack of further information it is offered as an approximate solution. We see in Table V. to what extent the values for the computed velocities check the experimental values. In all cases the velocity decreasing with increased wave-length of the exciting energy.

Now $1/t_m$ may be defined as the stopping power. So that the stopping power of the metal increases as the energy of the electron increases, to eventually approach a limiting value. Comparing these values we note that the heavier the atom the greater the stopping power. If we therefore compare the distance traveled in platinum to that in silver for electrons of equal initial velocity we find that the distance traveled in silver is 1.17 as great as that in platinum when the energy in each is reduced to the same amount. Hence if we compare equal volumes of the material traversed we find that the ratio of the atomic volumes of silver to platinum is 1.13 or of the same magnitude as the relative distances traveled in the two metals. So that electrons after traversing equal masses have their initial energies reduced to the same extent.

ABSORPTION COEFFICIENTS.

After passing through a thickness t_m the photoelectric thickness curve falls off slowly at first, then nearly linear and finally more slowly again

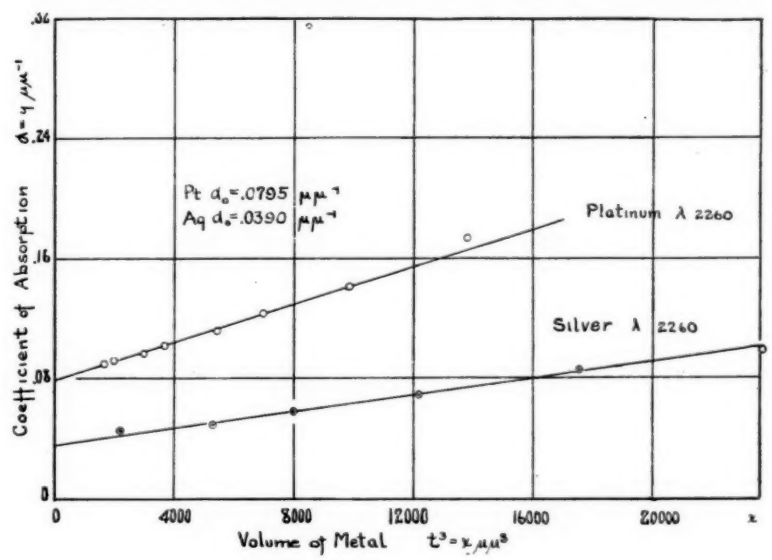

Fig. 9.

cutting the thickness axis at what appears to be a finite value. Unfortunately the latter part of the curve was very difficult to determine

owing to the very minute number of electrons coming through such thick metallic layers.

The initial drop of the curve seems to indicate that there is little absorption of electron numbers as yet and that scattering is still predominant. From here on however the curve takes a very definite form. The problem is a very complex one, the steam of photoelectrons which are traveling in any given direction must suffer loss in numbers both through true absorption and scattering to such a degree as to completely disappear from the original direction and in doing so must lose energy as well. What the relative importance of these actions is in the present case is difficult to tell. A partial solution is however attempted.

The coefficients of absorption α were computed in the usual way for the absorption branch of the curve. These results were then plotted as ordinates and values of t, as abscissæ. The curve approximated nearest to a straight line when values of t^3 were used as shown in Fig. 9. Thus the relation $\alpha - \alpha_0 = mt^3$ would represent the relations to a comparative degree of accuracy limited by the experimental errors in the original observations. The values computed for α and values for m, the slope of the curves, are given for comparison, to show to what degree of accuracy the results may be valid.

TABLE VI.

Platinum, λ 226.			Silver, λ 226.		
a.	t.	m.	a.	t.	m.
.167 $\mu\mu^{-1}cm^{-1}$	24.0 $\mu\mu$	63.0 $\mu\mu^{-3}cm^{-3}$	.099 $\mu\mu^{-1}cm^{-1}$	29.5 $\mu\mu$	23.4 $\mu\mu^{-3}cm^{-3}$
.141	21.5	62.8	.083	26.0	25.0
.123	19.2	62.3	.070	23.0	25.4
.112	17.5	61.6	.059	20.0	25.0
.102	15.5	61.9	.050	17.5	20.5
.0972	14.5	60.0	.043	12.8	20.0
.0917	12.6	61.2			
.0907	11.8	68.0			
	Mean	62.6 $\mu\mu^{-3}cm^{-3}$		Mean	23.2 $\mu\mu^{-3}cm^{-3}$

The coefficients of absorption thus obtained are not constant, but increase very rapidly with increasing values of thickness traversed. The intercepts on the y axis are however of interest. They would represent the absorption coefficients for values of thickness commensurable to a molecular layer. These values of α_0 for platinum and silver were found to be .0795 and .0390 $\mu\mu^{-1}$ respectively for photoelectrons emitted with a velocity of 13×10^7 cm. per sec. from their parent atoms. If we divide

the above values by the density of the respective metals to which they apply we arrive at the following interesting relation

$$\left(\frac{\alpha_0}{\rho}\right)_{Pt} = 37{,}000 \text{ cm}^2\text{gm}^{-1},$$

$$\left(\frac{\alpha_0}{\rho}\right)_{Ag} = 37{,}100 \text{ cm}^2\text{gm}^{-1},$$

showing the mass absorption to be constant for λ 226. This is the "density law" of absorption at first suggested by Lenard.[1] Crowther,[2] experimenting with β rays from uranium showed that the "density law" did not hold for these larger velocities. Lenard experimenting with heterogeneous cathode rays arrived at the following values for the metals gold and silver here given for comparison.

$$\frac{\alpha_0}{\rho} = 2880 \text{ cm}^2\text{gm}^{-1},$$

$$\frac{\alpha_0}{\rho} = 3070 \text{ cm}^2\text{gm}^{-1}.$$

Compton and Ross working with sputtered platinum obtained from photoelectric measurements the average value $\alpha/\rho = 28{,}900$. While Partzsch and Hallwachs (*l. c.*), using some data supplied by Rubens and Ladenburg, obtained the value $\alpha/\rho = 47{,}400$ for gold in the form of a leaf of about 100 $\mu\mu$ thickness.

The exigencies of the times have interrupted the completion of this subject at this time, it is hoped however that in the near future further data can be published which will support the above conclusions. The experimental part of this paper was performed at the University of Pennsylvania and I take great pleasure in acknowledging the ever generous coöperation of Prof. Goodspeed in furnishing the funds for the necessary apparatus.

[1] Lenard, *l. c.*

[2] Crowther, Phil. Mag., 12, p. 379, 1906.

THE PHYSICS LABORATORY,
STATE UNIVERSITY OF IOWA,
IOWA CITY, IOWA.

WALLACE CLEMENT SABINE.

WALLACE CLEMENT SABINE, Hollis Professor of Mathematics and Natural Philosophy at Harvard University and formerly dean of the Harvard Graduate Schools of Applied Science, Vice-President of the American Physical Society and recent member of the editorial board of the PHYSICAL REVIEW, died at Boston on the tenth day of January, 1919, in his fifty-first year.

PROCEEDINGS

OF THE

AMERICAN PHYSICAL SOCIETY.

MINUTES OF THE PITTSBURGH MEETING, December 27–29, 1917.

THE ninety-second meeting of the American Physical Society (the nineteenth Annual meeting) was held in the Applied Science Building of the Carnegie Institute of Technology, December 27 to 29, 1917. This was a joint meeting with Section B (Physics) of the American Association for the Advancement of Science. Two sessions were held on each of the three days of the meeting, Thursday, Friday, and Saturday.

On the first two days the following program of research papers was presented. This program was in charge of the officers of the Physical Society.

The Optical Properties of Rubidium. J. B. NATHANSON.

A Preliminary Study of the Luminescence of the Uranyl Salts Under Cathode Ray Excitation. FRANCES G. WICK and LOUISE S. MCDOWELL.

Note on a Phosphorescent Calcite. E. L. NICHOLS and H. L. HOWES.

The Visibility of Radiation in the Blue End of the Visible Spectrum. L. W. HARTMAN.

An Improved Form of Mercury Vapor Air Pump. CHAS. T. KNIPP.

Heat Conductivity of Cerium. C. N. WENRICH and G. G. BECKNELL.

Temperature and Heat of Fusion. J. E. SIEBEL. (By title.)

Report on the Construction of Certain Mathematical Tables. C. E. VAN ORSTRAND.

Mobilities of Ions in Vapors. KIA-LOK YEN.

The Size and Shape of the Electron. ARTHUR H. COMPTON.

The Coefficient of Emission and Absorption of Photo-electrons from Platinum and Silver. OTTO STUHLMANN, JR.

Ionization and Excitation of Radiation by Electron Impact in Nitrogen. BERGEN DAVIS and F. S. GOUCHER.

Energy in Continuous X-Ray Spectra. C. T. ULREY.

An Experimental Investigation of the Characteristic X-Ray Emission from Molybdenum and Palladium. BENJAMIN A. WOOTEN.

Characteristic X-Ray Emission as a Function of the Applied Voltage. BERGEN DAVIS.

A Standard of Sound. (Demonstration.) CHAS. T. KNIPP.

The Air Damped Vibrating System: Theoretical Calibration of the Condenser Transmitter. I. B. CRANDALL.

A Photographic Method of Measuring the Velocity of Sound Waves near the Source of Sound. ARTHUR L. FOLEY. (By title.)

The Effect of Intensity and Distance on the Velocity of Sound. ARTHUR L. FOLEY. (By title.)

The Influence of the Pressure and Time Employed in Condensing a Dental Amalgam upon its Crushing Strength, at Temperatures Between 10° and 100° C. ARTHUR W. GRAY and PARIS T. CARLISLE.

Absorption in Paraffined Paper Condensers. L. PYLE.

An Interesting Case of Resonance in an Alternating Current Circuit. H. K. DODGE.

On Electromagnetic Induction and Relative Motion, II. S. J. BARNETT.

Eddy-current and Hysteresis Losses in Iron at High Frequencies. C. NUSBAUM.

Some Energy Transformations with Oscillatory Currents. E. F. NORTHRUP.

The Effects produced upon Audion Characteristic Curves by Different Kinds of Signals (Buzzer, Electron Relay and 60-cycle A.C.) A. D. COLE.

Influence of a Series Spark on the Direct Current Corona. S. F. CROOKER. (By title.)

On the Effect of a Magnetic Field upon Cathode Rays. L. T. MORE and LOWELL M. ALEXANDER. (By title.)

The Physical Characteristics of X-Ray Fluorescent Intensifying Screens. MILLARD B. HODGSON.

Barometric Ripples. W. J. HUMPHREYS.

The Ultra-Violet and Visible Absorption Spectra of Phenolphthaleins. W. E. HOWE and K. S. GIBSON.

The Ultra-violet and Visible Absorption Spectra of Orcinolphthaleins. R. C. GIBBS, H. E. HOWE and E. P. T. TYNDALL.

The Ultra-Violet Absorption Spectra of Acetone. E. P. T. TYNDALL.

Thermal Conductivity of Metals. EDWIN H. HALL. (By title.)

A Mercury Manometer of High Sensibility. J. E. SHRADER.

A Simple Gauge for Very Low Pressures. J. E. SHRADER.

Resonance and Ionization Potentials for Electrons in Magnesium Vapor. PAUL D. FOOTE and F. L. MOHLER.

The Spectral Photoelectric Sensitivity of Molybdenite. W. W. COBLENTZ and M. B. LONG.

The program on Saturday was in charge of Section B, A.A.A.S. In the forenoon there was a symposium on "The Relationship of Physics to the War." Among the speakers were Lieut. G. P. Thomson, R.F.C. (son of Sir Joseph J. Thomson), Lieut. Giorgio Abeti of the Italian Mission to the United States, Dr. A. L. Day, Director of the Geophysical Laboratory, Washington, who gave an interesting account of the present optical-glass situation in this country and Major C. E. Mendenhall, who discussed the recent war activities of the National Research Council.

In the afternoon Professor Henry A. Bumstead delivered an address as

retiring Vice-president of Section B on "Present Tendencies in Theoretical Physics" (published in Science, January 18, 1918).

At a short business session of the Physical Society the result of the mail ballot for officers of the society for 1918 was announced. They are as follows: H. A. Bumstead, president; J. S. Ames, vice-president; D. C. Miller, secretary, and G. B. Pegram, treasurer. A. L. Day and G. F. Hull are the new members of the Council. (Former elected members holding over are C. E. Mendenhall, G. W. Stewart, I. Langmuir, G. B. Pegram, G. O. Squier and H. A. Wilson.) G. K. Burgess, A. C. Lunn and A. D. Cole are the newly elected members of the Editorial Board of the PHYSICAL REVIEW. (Former members of the board holding over are F. Bedell, Managing Editor, and E. P. Lewis, W. C. Sabine, A. Trowbridge, N. E. Dorsey, Wm. Duane and O. M. Stewart.)

The reports of the treasurer and managing editor were presented, accepted, and ordered printed. (These printed reports were afterward mailed to all the membership.)

The visiting members of the Society were much indebted to Dean F. L. Bishop of the University of Pittsburgh and to Prof. H. S. Hower, of the Carnegie Institute of Technology, and to other resident members for many courtesies extended to them.

ALFRED D. COLE,
Secretary for 1917.

MINUTES OF THE BALTIMORE MEETING, DECEMBER 27 AND 28, 1918.

THE ninety-fifth meeting (the twentieth annual meeting) of the American Physical Society was held at Johns Hopkins University, in Baltimore, Maryland, on December 27 and 28, 1918, in affiliation with Section B—Physics of the American Association for the Advancement of Science. Professor Bumstead is now serving as Scientific Attaché to the American Embassy in London and his resignation as president of the society was accepted by the Council on November 30, 1918. The vice-president, J. S. Ames, thus became acting president, and he presided at the several sessions of the society and the council. The maximum attendance at the technical meetings was about one hundred, while eighty-eight members and visitors were present at the time of the business session.

On the afternoon of December 27 there were two sessions under the auspices of Section B, the presiding officer being the vice-president and chairman of the section, Major G. F. Hull. At two o'clock, p.m., the retiring vice-president and chairman W. J. Humphreys, gave an address on "Some Recent Contributions to the Physics of the Air." At five o'clock, p.m., Dr. George E. Hale gave an address before the entire Association on "The National Research Council."

The annual business meeting was held at eleven o'clock, a.m., on December 28, 1918. The revised form of the Constitution and By-Laws was unanimously adopted by letter ballot. The amendments do not alter the intent or purpose

of the constitution in the old form, except in one respect; the managing editor is made a member, *ex-officio*, of the council. The amended constitution will be published in the next printed list of members.

The following officers were elected for the year 1919: For President, J. S. Ames; for Vice-President, W. C. Sabine; for Secretary, D. C. Miller; for Treasurer, G. B. Pegram; for Members of the Council (four-year term), G. K. Burgess, J. C. McLennan; for Member of the Council (one-year, unexpired term), Max Mason; for members of the Board of Editors of the PHYSICAL REVIEW, Henry Crew, L. V. King, H. S. Uhler.

Colonel Millikan explained the purposes of the Smith-Howard Bill now before Congress, authorizing Federal coöperation with the States for the promotion of engineering and industrial research. After general discussion it was unanimously voted that the American Physical Society favors federal aid and coöperation with the several States in support of research in science and engineering and in industrial research. The society favors the creation of Boards of eminent scientists and engineers within each state for the administration of the funds appropriated for all research within the state.

The reports of the treasurer and of the managing editor of the PHYSICAL REVIEW were presented at the meeting of the council. It was ordered that, after auditing, these reports be printed and sent to all members.

The secretary reported that within the year sixty-two persons had been elected to associate membership and eight elected to regular membership. Eighteen associate members had been transferred to regular membership. There was one resignation from membership. Two members had died within the year, C. C. Trowbridge, and Ernest Weibel, the latter having been killed in action in France. The total membership now is 935, there being 402 regular members.

As a matter of record it is noted that, because of conditions growing out of the war, three meetings, which, following custom, would have been held in the year 1918, were cancelled. These meetings were the usual Washington meeting of April, a special joint meeting with the American Institute of Electrical Engineers which had been arranged for October 11 and 12, and the Chicago meeting of November 30. A special meeting of the council was held in Baltimore on November 30, 1918, to transact necessary business.

At a meeting of the Council held in Baltimore on November 30, 1918, the following elections were made: *elected to regular membership*, Shoji Nishikawa; *elected to associate membership*, W. F. Angell, H. C. Arnold, J. W. Cook, F. A. Ferguson, O. F. Gish, Peter Hidnert, Samuel C. Hoffman, Frank C. Hoyt, I. L. Jones, Lewis V. Judson, Herbert Kahler, Charles B. Kazda, Otto Koppius, M. B. Long, John P. Minton, Newell C. Page, Herbert H. Palmer, Arthur R. Payne, C. E. Pierce, Anthony S. Santos, C. D. Shallenberger, Joseph Valasek, Hugo P. Wahlin, Dorothy W. Weeks, W. Wubbe.

At a meeting of the Council held in Baltimore on December 27, 1918, the following elections were made: *elected to regular membership*, M. D. Hershey,

J. C. Hunsaker, Vladimir Karapetoff, Paul D. Merica, John M. Miller, H. B. Phillips; *elected to associate membership*, R. C. Colwell, Wm. B. Creagmile, G. A. Dasney, A. E. F. Fant, E. O. Hoffman, J. J. Hopfield, F. L. Hunt, George Lewis, H. J. Lockwood, C. W. D. Parsons, D. E. Sharp, Margery Simpson, Marguerite D. Tschaler, I. H. Van Horn, F. C. Wente, C. F. Whittemore, D. T. Wilber; *transferred from associate to regular membership*, E. C. Crittenden, A. T. Jones, E. F. Kingsbury, Louise S. McDowell, Wm. F. Meggers, A. Norman Shaw, H. B. Williams.

At the morning sessions of December 27 and 28, 1918, thirty papers were presented as follows, four being read by title:

The Unique System of Units. W. W. Strong.

A Simple Stretched Wire Dilatometer. Arthur W. Gray.

Monochromatic and Neutral Tint Screens in Optical Pyrometry. W. E. Forsythe.

The Temperature, Pressure, and Density of the Atmosphere in the Region of Northern France. W. J. Humphreys.

Refinements in Spherometry. G. W. Moffitt.

A New Type of Hot Wire Anemometer. T. S. Taylor.

The Linear Thermal Expansion of Glass at High Temperatures. C. G. Peters.

Some Characteristics of Glasses in the Annealing Range. A. Q. Tool and J. Valasek.

Striæ in Optical Glass. L. E. Dodd and A. R. Payne.

Preliminary Determination of the Thermal Expansion of Molybdenum. Lloyd W. Schad and Peter Hidnert.

On the Characteristics of Electrically Operated Tuning Forks. H. M. Dadourian. (Read by title.)

Ionization and Resonance Potentials for Electrons in Vapors of Arsenic, Rubidium, and Caesium. Paul D. Foote, O. Rognley and F. L. Mohler.

Absorption Coefficient of the Penetrating Radiation. Oliver H. Gish.

Photoelectric Sensitivity vs. Current Rectification in Molybdenite. W. W. Coblentz and Louise S. McDowell.

A Device for the Automatic Registration of the α- and β-Particles and γ-Ray Pulses. Alois F. Kovarik.

Note on the Distribution of Energy in the Visible Spectrum of a Cylindrical Acetylene Flame. Edw. P. Hyde, W. E. Forsythe and F. E. Cady.

Preliminary Note on the Luminescence of the Rare Earths. E. L. Nichols, D. T. Wilber and F. G. Wick.

On the Critical Absorption Frequencies of Chemical Elements of High Atomic Numbers. William Duane and Takio Shimizu.

Some Interesting Results of Eclipse Magnetic Observations. L. A. Bauer.

The Minimum Temperature at the Base of the Stratosphere. W. J. Humphreys. (Read by title.)

Why Clouds Never Form in the Stratosphere. W. J. Humphreys. (Read by title.)

Speeds in Signaling by the Use of Light. W. E. FORSYTHE.

Thermal Conductivity of Various Materials. T. S. TAYLOR.

Further Observations on the Production of Metallic Spectra by Cathode Luminescence. EDNA CARTER and ARTHUR S. KING.

Effect of Crystal Structure Upon Photoelectric Sensitivity. W. W. COBLENTZ. (Read by title.)

A Mechanically Blown Wind Instrument. A. G. WEBSTER.

The Dynamics of the Rifle Fired at the Shoulder. A. G. WEBSTER.

Interior Ballistics, by a New Gun Indicator. A. G. WEBSTER.

Residual Gases in Highly Exhausted Glass Bulbs. J. F. SHRADER.

Silvering Quartz Fibers by Cathodic Sputtering. J. F. SHRADER.

DAYTON C. MILLER,
Secretary.

THE SPECTRAL PHOTOELECTRIC SENSITIVITY OF MOLYBDENITE.[1]

BY W. W. COBLENTZ AND M. B. LONG.

THE samples of molybdenite MoS_2, examined were thin folia, 0.01 to 0.05 mm. in thickness, soldered to copper electrodes.

In this examination, which is of a preliminary nature, the sample of molybdenite was exposed to radiations of equal energy (measured with a thermopile) of different narrow spectral regions, isolated by means of screens. These bands of spectral radiation, having their maximum intensity at wave-lengths λ_m = 0.5, 0.55, 0.6, 0.75, 0.9, 2.4, 4.4 and 8.5 μ respectively, were obtained by transmission of the radiations from a Nernst glower through colored glasses, by the emission from the Bunsen gas flame and by utilizing residual radiations reflected from quartz.

The results obtained indicate that molybdenite, like selenium and stibnite, has its maximum photoelectric sensitivity just beyond the visual red, 0.85 μ; but it differs from these substances in that it is quite sensitive to infra-red rays. For example, at 2.0 μ the photoelectric sensitivity is perhaps from one third to one half that of the maximum, and at 4.4 μ (Bunsen flame which has weak emission bands at 1.8 and 2.7 μ) it is about one tenth the maximum.

The temperature coefficient of resistance of molybdenite is negative; and hence a rise in temperature produces a change in resistance which is in the same direction as that caused by the photoelectric effect. It will therefore be necessary to determine the magnitude of these two effects in order to establish a true photoelectric effect for wave-lengths greater than 4.4 μ. These various factors including reflection, etc., will be considered in the complete paper.

WASHINGTON, D. C.
December 22, 1917.

[1] Abstract of a paper presented at the Pittsburgh meeting of the American Physical Society, December 27–29, 1917.

THE UNIQUE SYSTEM OF UNITS.[1]

BY W. W. STRONG.

SOME thirty years ago it would have almost been universally admitted by physicists and chemists that all masses were integral multiples of the masses of the atoms constituting the given mass. The masses of the atoms were universal invariants and an atomic system of units of this kind has been proposed. The effort of Prout was that of making a unique and universal atomic unit of mass that could be used wherever matter is present.

Today it is almost universally assumed that the charge of the electron is a unit of electrical charge in much the same way as the atomic unit of mass in the system of Prout. The variable mass of the electron as its velocity changes indicates that if there is an invariable element of mass it is much smaller than Prout imagined and that it cannot be larger than that quantum of mass that appears when the electron is accelerated. Let us assume that there are such invariant quanta of electrical charge and mass. If some five such invariant quantities as we may consider as applying to electrical charge, mass quanta and radiant energy (with a supposed constancy of the velocity of light) were consistent with phenomena we would be approaching a unique set of units. Let us then state some of the properties of such an ideal system of units.

1. There are in nature certain invariant atomic quantities that serve as the basis for a unique and a universal system of units that is absolute in reality. At the present time the electron (unit) is usually made to play such a rôle.

2. The science of measurement is not then based upon a complicated and an artificial process of creating and comparing standards and in defining terms such as the coincidence of two events or of comparing two lengths in relative motion but upon a unique set of natural and invariant units that are universally available.

3. If there is an ether it appears logical to assume that this set of unique units should be provided for us by the structure of the ether or at least as many of them as are necessary to fully describe all phenomena relating to the ether, the electric, magnetic and gravitational fields. Derived units such as T and L should be based on an ether structure since these are used in treating the propagation of light.

4. The unique set of units are made so by all phenomena being consistent with the assumption of their being unique and hence their use is supported by all scientific knowledge. If all electrons are alike there is no necessity of defining equal charges of electricity as is done in connection with the derivation of the electrostatic system of units. If there is an elementary quantum of mass there is no necessity to consider the matter of relative motion in the definition of mass. How can a consistent system of units be obtained by assuming the Newtonian mechanics in the definition of our units and the de-

[1] Abstract of a paper presented at the Baltimore meeting of the American Physical Society, December 27, 1918.

scription of phenomena and then trying to build a relativity theory on another system of mechanics and at the same time using the old system of units?

5. The derived units should be uniquely determined by the fundamental or natural unique units.

6. It hardly seems possible to develop a consistent system of physics without at first determining a system of units that is universally applicable to all phenomena to be investigated.

S. I. E. M. Co.,
MECHANICSBURG, PA.

A SIMPLE STRETCHED WIRE DILATOMETER.[1]

BY ARTHUR W. GRAY.

AT the request of Dr. Arthur L. Day, Optical Glass Committee, War Industries Board, the writer undertook to determine the thermal expansivity of some optical glass which had been produced under the direction of the former for naval searchlight mirrors. The decision as to whether or not the glass was suitable rested exclusively upon its thermal expansivity, a knowledge of which was desired up to about 200° C. With the dilatometer which had to be hastily constructed for the purpose, expansions were, however, measured at various temperatures up to 300° C.

The apparatus, which uses the stretched wire method of measuring linear displacements,[2] could easily be adapted for commercial testing. It differs from the precision apparatus developed by the writer at the Bureau of Standards, mainly in the substitution of an ordinary Brown and Sharpe micrometer screw for the expensive microscope comparator and reference bar.

Extending vertically downwards from the cover of the temperature bath are two tubes, the axes of which are separated by approximately the length of the specimen under investigation. At the lower end of each tube are two pointed co-axial screws for clamping the specimen from opposite sides. One of the tubes is rigidly attached to the cover, the other is hinged so as to permit free expansion of the specimen. A fine wire, of annealed tungsten, attached to the lower end of each tube extends vertically upwards through the tube and the cover for several decimeters above the latter, where it passes over a pulley and supports a weight which keeps it tight and straight. The wire bears firmly against the rounded end of the specimen and likewise against a round

[1] Abstract of a paper presented at the Baltimore meeting of the American Physical Society, December 27, 1918.

[2] Expansion measurements by this method were reported to the Physical Society at the Washington meeting in December, 1911, and at various times since then. The principle was also described in a communication to the Washington Academy of Sciences, in which the two arrangements that form the basis of the Bureau of Standards' present expansivity equipment were illustrated diagrammatically. (A. W. Gray, "New Methods for Displacement Measurements and Temperature Uniformity Applied to the Determination of Linear Expansivity," Journ. Wash. Acad. Sc., 2, 248–258, 1912.) One arrangement is used with electric furnaces, the other with liquid baths.

pin situated a decimeter or so below the pulley. By means of a micrometer screw and suitable guides this pin is movable horizontally in the plane of the two wires, so that their upper ends can be brought closer together or separated a measured distance. Just above the cover of the temperature bath is placed a horizontal bar of low and known thermal expansivity, protected as far as possible from temperature changes accompanying warming and cooling of the bath below.

After the specimen is placed in the temperature bath, the upper end of each stretched wire is moved until the wire just touches the end of the bar above the cover. Contact is indicated electrically by means of an inexpensive reflecting galvanometer in series with a dry cell and a suitable resistance. As the specimen under investigation expands, it moves the wires away from the contact bar. The magnitude of the expansion is determined from the movements of the micrometer screws required to restore contact.

Only one graduated screw is actually used. An ordinary screw of moderately fine pitch moves a horizontal bar to which are rigidly attached both the pin that communicates the motion to the left-hand wire *A* and the nut of the graduated screw which moves the right-hand wire *B*. In this way a single micrometer screw is made to measure the total displacement of both wires.

The accuracy of the apparatus just described is limited mainly by the accuracy with which contact can be detected between the stretched wires and the bar above the temperature bath. The effect of errors in the measuring screw varies inversely as the ratio of the distances from the contact bar to the pins for moving the wires and to the specimen. In the apparatus actually used these pins were 600 mm. above and the specimen 150 mm. below the bar, so that the micrometer screw measured four times the expansion of the specimen. The results showed that with proper use deviations of individual screw readings from the average should not exceed 5 microns. The average deviation of 107 individual readings from the average reading for each temperature was less than 2 microns, corresponding to an average deviation of 0.5 micron in determining the expansion of the specimen.

The apparatus actually constructed as outlined above illustrates merely one particular arrangement for applying the general principles of the method. It was hastily designed and built to meet an emergency. Various details could obviously be modified. For example, two independent graduated screws for moving the stretched wires *A* and *B* would be a convenience; any sensitive detector of contact is usable; tungsten wires are not necessary, etc. Moreover, micrometer screws can be arranged to replace microscopes for use with either an air-bath (as in an electric furnace) or a liquid bath; so that the range of application is not limited to the interval between room temperature and 300° C.

PHYSICAL RESEARCH LABORATORY,
THE L. D. CAULK COMPANY,
MILFORD, DELAWARE,
Nov. 29, 1918.

MONOCHROMATIC AND NEUTRAL TINT SCREENS IN OPTICAL PYROMETRY.[1]

BY W. E. FORSYTHE.

IT is very difficult to find a monochromatic or a neutral tint glass screen for optical pyrometry. Very fortunately absolutely monochromatic or absolutely neutral tint screens are not necessary for such work. For the so-called monochromatic screen what is wanted, for the most part, is a screen that is sufficiently monochromatic to enable comparisons in brightness to be made between the comparison source, or pyrometer filament for the Morse pyrometer, and the source that is being investigated.

When it is necessary to use glass absorbing screens to reduce the apparent brightness of the source studied, the main requirement is to have a screen that is nearly enough neutral tint to permit comparisons in brightness to be made. The degree to which it is necessary for the absorbing screen to have a spectral transmission independent of the wave-length, depends upon the so-called monochromatic glass used. It is quite evident that if the colored glass used is absolutely monochromatic, any absorbing glass would answer.

With two pieces (thickness about 6 mm.) of Jena red glass no. 4512 in the eyepiece of the pyrometer the total transmission, which amounted to about 1.5 per cent., of a piece of noviweld absorbing glass was measured for a particular temperature by two observers whose visibility curves are quite different and the two results agreed to within a fraction of a per cent. If a red glass is used, by total transmission is meant the ratio of the brightness observed through the red glass and the black glass to the brightness observed through the red glass alone. If the entire visible spectrum is used, it is generally very hard to make such measurements owing to the color differences involved with even the best absorbing glasses. If, however, a good red glass is used in the eyepiece, transmission measurements can easily be made.

The transmission of the absorbing glass when used with a red glass can be calculated for any black body distribution by the following formula taken from Preston's theory of light:

$$(1) \qquad T_B = \frac{\int J_\lambda V_\lambda T'_R T'_B d\lambda}{\int J_\lambda V_\lambda T'_R d\lambda}.$$

$J_\lambda d\lambda$ = black body energy for interval λ to $\lambda + d\lambda$, V_λ = visibility, T_R' and T_B' = spectral transmission of red and absorbing glasses respectively. An absorbing glass that is not neutral tint is sometimes used to cut down the apparent brightness of a source when measuring the temperature with an optical pyrometer having a red glass in the eyepiece. It has been stated[2] that if an absorbing glass which is not neutral tint is used in connection with the red glass, the effective wave-length to be used is different from the effective wave-length that is to be used with a sector. In what follows it is shown that

[1] Abstract of a paper presented at the Baltimore meeting of the American Physical Society, December 27, 1918.

[2] Foote, Bull. Bureau of Standards, Vol. 12, p. 491.

such is not the case but that the same effective wave-length is to be used in each case. Suppose that a sector with a transmission T_S were found such that the brightness observed through the sector would equal that observed through the black glass using the same red glass in both cases, that is

$$\int J_\lambda V_\lambda T'_B T'_R d\lambda = \int J_\lambda V_\lambda T'_R T_S d\lambda = T_S \int J_\lambda V_\lambda T'_R d\lambda.$$

The question to be considered is what effective wave-length is to be used in calculating the temperature of the source whose brightness is thus measured. When the brightness is measured using the rotating sector the temperature T_2 is calculated from T_1 the temperature corresponding to the pyrometer reading if no sector is used by means of the formula

$$1/T_2 - 1/T_1 = \frac{\lambda_e \log T_S}{c_2 \log e}, \tag{2}$$

when T_S = transmission of sector λ_e the ordinary effective wave-length between T_1 and T_2. The effective wave-length has been defined as the wave-length such that

$$\left[\frac{J(\lambda, T_1)}{J(\lambda, T_2)}\right]_{\lambda_e} = \frac{\int J(\lambda, T_1)\, V_\lambda T_R' d\lambda}{\int J(\lambda, T_2)\, V_\lambda T_R' T_S d\lambda}.$$

T_S = transmission of sector. Suppose that using the black glass screen before the pyrometer lamp the same current A through the pyrometer filament is required to cause an apparent brightness match between the same source at temperature T_2 and the pyrometer filament. This means that the sector and glass have the same transmission. The temperature T_2 can be calculated by an equation similar to equation (2).

$$1/T_2 - 1/T_1 = \frac{\lambda'_e \log T_B}{c_2 \log e}. \tag{3}$$

T_B = transmission of black glass screen and λ_e' an effective wave-length. As T_1 and T_2 are the same in each case

$$\lambda_e \log T_S = \lambda_e' \log T_B,$$

or

$$\lambda_e = \lambda_e',$$

that is, as the transmission of the black glass given by equation (1) is the same as would be obtained by comparing the transmission of the glass with a sector the same wave-length is to be used in each case.

Nela Research Laboratory,
National Lamp Works of General Electric Company,
Nela Park, Cleveland, Ohio,
December, 1918.

THE TEMPERATURE, PRESSURE AND DENSITY OF THE ATMOSPHERE IN THE REGION OF NORTHERN FRANCE.[1]

BY W. J. HUMPHREYS.

THE records of 416 sounding balloon flights made at Trappes, Uccle, Strassburg and Munich during the years 1900–1912 have been grouped in such manner as to give the average summer and winter distribution of temperature, humidity, pressure and density from the surface up to 20 kilometers above sea level. The temperatures have further been grouped according to weather conditions.

All this data is given in brief tables and shown in graphs.

A NEW TYPE OF HOT WIRE ANEMOMETER.[1]

BY T. S. TAYLOR.

IN all hot wire anemometors thus far used, the instruments have been so designed as to measure the average velocity over the area of the pipe or for a length of 10 cm. or greater at different points in the plane of cross section. None of these types is suitable for the measurement of velocity in small tubes. It was for the purpose of making these latter measurements, that the present instrument was constructed. It consists of a platinum heating wire 0.007 inch in diameter and one half to one inch long, stretched across a suitable framework, say of glass, and having a copper-constantan thermocouple made of .002 inch wire attached at its mid point. The instrument can be used satisfactorily by measuring the current that is necessary to maintain the temperature, as determined by the thermocouple, say 300° C., above the temperature of the gas in which it is placed. This method facilitates the measurements greatly, and avoids the possibility of accidentally burning out the wire. As for the other types of anemometers, it is necessary to calibrate it under the conditions under which it is to be used. This can be done by revolving it at various speeds in the gas whose velocity is to be measured at various temperatures. To do the latter it is necessary to have the revolving part of the calibration device contained in an oven whose temperature can be regulated quite accurately.

By using this method it is possible to measure quite accurately the velocity of gases at various temperatures, and has the great advantage of really measuring the velocity of gas at a point.

A second type, constructed after the usual one, has also been used in exactly the same manner as the above. It determines the average velocity over a length of from one to three millimeters. It is constructed by having two small .002-inch platinum wires attached about 2 millimeters apart near the middle of the .007-inch platinum heating wire. In calibrating and using it, the cur-

[1] Abstract of a paper presented at the Baltimore meeting of the American Physical Society, December 27, 1918.

rent is measured that is required to maintain a certain potential drop, say 60 millivolts between the two potential leads. A good portable potentiometer such as Leeds and Northrup's potentiometer indicator is suitable both for the temperature measurements in the first type and the potential drop in the second type. The current can be measured quite satisfactorily by use of a good ammeter of proper range. To be sure more accurate results can be obtained when the measurements of both current and potential or thermal electromotive force are made by means of a precision potentiometer.

A decided advantage of the thermocouple type is that it enables one to determine the temperature of the gas directly, immediately before or after taking velocity measurements. This can be done also for the second type by the insertion of a separate thermocouple near the resistance wire or from the temperature coefficient of the platinum wire.

December 3, 1918.

The Linear Thermal Expansion of Glass at High Temperatures.[1]

By C. G. Peters.

THE thermal expansions of different kinds of optical glass, chemical glassware, and ordinary glass tubing, were measured by the Fizeau method. Rings cut from the samples were placed between two fused quartz interferometer plates and heated in an electric furnace from 20° to 650° C. Curves with degrees Centigrade plotted against increase in length show that the rate of expansion of each sample was nearly constant until the annealing temperature was reached. This annealing temperature varied with different glasses from 450° to 550° C. After the annealing temperature was passed the glass seemed to be in a slighty plastic condition and the rate of expansion increased by four to six times. This rapid expansion continued for about 100° when a softening point was reached. From the curves the temperature where careful annealing is required can be accurately located.

Bureau of Standards,
Washington, D. C.

Some Characteristics of Glasses in the Annealing Range.[1]

By A. Q. Tool and J. Valasek.

A STUDY has been made of the behavior of a number of glasses near their softening temperatures in order to obtain data that would serve to indicate the proper annealing process, as well as the maximum temperatures at which the various glasses should be annealed.

The " relaxation times " for the stresses were determined by two methods, the first being by the bending of a glass strip as described by Twyman and the

[1] Abstract of a paper presented at the Baltimore meeting of the American Physical Society, December 27, 1918.

second by observing the rate at which the double refracting power of a sample of strained glass disappeared. This relaxation time T, defined by the equation

$$\frac{dF}{dt} = E\frac{ds}{dt} - \frac{F}{T}$$

due to Maxwell, decreases with increasing temperature in such a way that

$$T_\theta = T_0 e^{(\theta_0 - \theta)/k}.$$

The magnitude of the constant k was found to depend on the nature of the glass. For optical glasses it was found to range from 10 to 13 for temperatures expressed in degrees Centigrade.

In the temperature range where the glass softens to such a degree that T becomes only a few tenths of an hour, it was found that heating curves, obtained by the use of a differential couple, showed a relative cooling of the glasses with respect to the neutral body. Cooling curves show a relative heating.

Measurements by C. G. Peters, of this bureau, have shown that in this same range there is an abnormal increase in the expansion coefficient. Consequently it is to be suspected that the softening of the glass, the increased expansion and this apparent cooling effect are closely related.

HIGH TEMPERATURE MEASUREMENT SECTION,
BUREAU OF STANDARDS,
WASHINGTON, D. C.

PRELIMINARY DETERMINATION OF THE THERMAL EXPANSION OF MOLYBDENUM.[1]

BY LLOYD W. SCHAD AND PETER HIDNERT.

THE thermal expansion of an exceptionally pure specimen of molybdenum was determined from $-142°$ to $+305°$ C.

A short description of the apparatus and of the method used in obtaining high and low temperatures is given.

The results are shown in the form of tables, from which were computed by the method of least squares, the two following empirical equations which satisfy the observations:

$$L_t = L_0 (1 + 5.15t \times 10^{-6} + 0.00570t^2 \times 10^{-6})$$

and

$$L_t = L_0 (1 + 5.01t \times 10^{-6} + 0.00138t^2 \times 10^{-6}),$$

where L_t is the length of the specimen at any temperature t within the proper range; in the first case 19° to $-142°$ C. and in the second case 19° to $+305°$ C. The probable error of the length computed from these equations is less than 3×10^{-6} per unit length.

[1] Abstract of a paper presented at the Baltimore meeting of the American Physical Society, December 27, 1918. Complete paper may be found in the Scientific Papers of the Bureau of Standards, No. 332.

Speeds in Signaling by the Use of Light.[1]

By W. E. Forsythe.

In connection with some other work it was necessary to have some data concerning the maximum speed of light signaling as limited by the inertia of the eye and to compare this with the speeds attainable with various types of lamps.

A preliminary investigation was carried out to determine the relative lengths of dot, space and dash necessary for the greatest speed. Three observers made readings for this test and all agreed very well with the following ratio for the maximum speed:

dot: dash: space:: 1: 4: 3.

To test out the speed for a sharp cut off of the signals, using this ratio for dot, dash and space, a sector was made with which the following signals could be shown (space, of course, follows each dot or dash):

1—dot dash dot dash
2—dash dot dot dash
3—dash dot dot
4—dash dot dash dot
5—dash dash dot dot
6—dot dash dash dot
7—dot dash dash

This sector was mounted so that the observers saw the light source through a small opening. The observer was shown a series of twelve signals for each of a series of speeds beginning at a speed so low that there was no trouble in reading all the signals. This was repeated for higher and higher speeds until the observer was unable to read the signals.

To test out the speed where the heating and cooling of the different lamps was a factor, a commutator was constructed that would turn the lamps on and then off so that for any particular speed the voltage was applied to the lamp for the dot and dash the same length of time that the flashes of light were visible with the sector. Three observers made comparative readings on the signals as given by the sector and the commutator using a tungsten lamp with a ribbon filament mounted in argon. The results for each observer were about the same for either method.

As almost the same results were obtained from the lamp as from the sector this lamp, as a standard, was compared with a vacuum ribbon lamp and a gas-filled wire lamp. The lamps were so mounted as to have the same intensity in the direction of the observer stationed at a distance of 100 or 170 yards. Three observers took part in these tests and the results without exception were in favor of the gas-filled ribbon lamp.

[1] Abstract of a paper presented at the Baltimore meeting of the American Physical Society, December 27, 1918.

As all the above tests were carried out at a comparatively short distance it was thought well to make a test at a much larger distance. To do this the gas-filled ribbon lamp was mounted in a signaling unit which gave about a 5° spread and two observers made readings on signals sent as above at a distance of about 2,700 yards, both in the daytime and also at night. Assuming a breakdown at the speed at which two of the twelve signals shown were missed, one observer was able to read the signals on a clear day when the four-part signals were shown at such a speed that the time from the beginning to the end of the signal was about 1.6 seconds. This observer made about the same record at night. The other observer was able to read the signals on a clear day when the time from the beginning to the end of the signal was 2.2 seconds and at night his record was the same as that of the first observer.

A word might be said about how the signals appeared to the observer at the breakdown point. Each observer was instructed to record what he saw, not by code letter, but by actually writing down the dots and dashes. A study of these records shows that on clear days the breakdown seemed to be due to the observer's inability to see initial dots, finally seeing only the dashes. At night at the distance at which observations were made, the light was very intense and at the breakdown point the observers reported that they did not see the spaces between the light flashes. The light just seemed to flicker.

NELA RESEARCH LABORATORY,
NATIONAL LAMP WORKS OF GENERAL ELECTRIC CO.,
NELA PARK, CLEVELAND, OHIO,
December, 1918.

THERMAL CONDUCTIVITY OF VARIOUS MATERIALS.[1]

BY T. S. TAYLOR.

THE present investigation was undertaken to determine the thermal conductivity of various materials used in certain manufacturing processes. It was found that the direct method was by far the most satisfactory. This consisted of measuring the quantity of heat that passed through a given thickness of the material between two equi-temperature surfaces and the temperature drop through the sample. The hot equi-temperature surface or source consisted of a soapstone heater about 9 inches in diameter and 1/2 inch thick. It was composed of two discs each having a heating element wound in a spiral groove cut in its surface. The two discs were cemented together with faces having heating wire adjacent. Potential leads were brought out so that the potential drop could be determined for a determined area (about 4 sq. in.) surrounding the center of the heater. The cool equi-temperature surfaces were reservoirs through which water was kept circulating. The heat generated in the heater passed laterally through the samples to the cold reservoirs. The temperature drop through the samples was measured by means of small

[1] Abstract of a paper presented at the Baltimore meeting of the American Physical Society, December 27, 1918.

copper constant thermocouples inserted on each side of the sample. Extra turns of wire being wound around the outer edge of the heater made it possible to have the surface of the heater a very constant temperature source. Consequently from the amount of heat developed per unit area of the heater, the thickness of the sample and the temperature drop through the sample the thermal conductivity of the material is readily calculated.

By this method the conductivity of a large number of materials has been determined. The following list contains some of the results.

Material.	Thickness, Inches.	Direction of Heat Flow.	Temp.	Cal./cm. °C./sec.	Temp. Coef.
Hard rubber	0.380	Transversely.	25–50	0.000380	.0015
White fiber	0.383	"	20–80	0.000695	.0012
Woods:					
White pine	0.519	Across grain.	20–120	0.000255	.0015
" "	0.732	Along grain.	30–80	0.000613	.0020
Maple	0.508	Across grain.	20–80	0.000434	.0006
"	0.785	Along grain.	20–80	0.001037	.0008
White oak	0.516	Across grain.	20–80	0.000455	.0018
" "	0.754	Along grain.	40–70	0.000944	.0006
Plate Glass	0.252	Transversely.	20–100	0.00195	.0018
" "	0.289	"	20–120	0.00201	.0012
Soapstone	0.715	"	70–130	0.00800	
Sheet steel .0172 inch	0.416	Transversely.	20–80	0.00158	.0025
Same painted with asphalt	0.425	"	20–80	0.00625	.0009
Wool felt dark gray	0.98	"	40–100	0.000175	.0076
Solid graphite	1.04	"	50–130	0.110	.0012
Powdered graphite:					
1. through 20- on to 40-mesh	0.476	"	40–100	0.00320	.0048
II. through 40–mesh screen	0.476	"	40–100	0.00100	.0040
III. through 100	0.476	"	40–110	0.000482	.0034
Lamp Black:					
Eagle brand, Germantown	0.476	"	40–150	0.000166	.0006
Sil-O-Cel Brick	0.977	"	30–150	0.000262	.0015

The values as recorded are given in each case for the average temperature over which the observations extended. Thus for white pine the average temperature extended from 20° C. to 120° C. The conductivity as recorded is therefore for 70° C. The temperature coefficient of thermal conductivity was determined from the observations over the range of temperature in question.

One fact that is noticeable in particular is the amount the transverse thermal conductivity of iron sheets can be increased by painting the component sheets when building up the sample.

FURTHER OBSERVATIONS ON THE PRODUCTION OF METALLIC SPECTRA BY CATHODE LUMINESCENCE.[1]

BY EDNA CARTER AND ARTHUR S. KING.

IN continuation of previous experiments, the spectra of titanium, manganese, iron, magnesium, calcium and cadmium have been examined The metal was vaporized by the impact of cathode rays in a high vacuum and the spectrum of the vapor in the cathode stream observed. The later apparatus was constructed largely of quartz in order to withstand the considerable heating of certain parts.

The experiments have shown the possibility of obtaining by this method fairly rich spectra even for metals of high melting point. Thus for titanium about 140 lines were identified, and 150 for manganese. In the detailed publication a comparison will be made with the spectra of other sources. In general, the majority of lines in the luminescence spectrum are those easily excited in the arc and furnace, but peculiarities appear which mark this as a source having special characteristics, and the action appears to be materially different for different vapors. For titanium the spectrum closely resembles that of the furnace, the enhanced lines being absent, while with cadmium, magnesium, and calcium there is a marked tendency to show enhanced lines. A relatively high intensity of lines in the ultra-violet was noted.

In the regular arrangement, the vapor whose spectrum was photographed was out of the path of the current, the anode being at one side of the chamber. When the anticathode was used as the anode, a much more intense spectrum was obtained, but for the elements tested, no decided difference in relative intensity of lines was observed. A discharge of this kind gave about 120 lines in the iron spectrum, the relative intensities among these lines showing many features of interest. Certain groups are strongly emitted, some of these being characteristic of low temperature conditions, while others require in other sources an intense excitation. In further work, the discharge conditions governing the appearance of certain classes of lines will be more fully tested.

VASSAR COLLEGE,
MOUNT WILSON SOLAR OBSERVATORY,
December, 1918.

RESIDUAL GASES IN HIGHLY EXHAUSTED GLASS BULBS.[1]

BY J. E. SHRADER.

THE investigation of high vacua has been extended by making observations on the effect of the sealing off of highly exhausted glass bulbs, and noting the subsequent change in pressure with time over an extended period.

In this work the mercury diffusion pump and the Knudsen Absolute gauge were employed. The glass ware was cleaned with potassium bichromate

[1] Abstract of a paper presented at the Baltimore meeting of the American Physical Society, December 27, 1918.

solution followed by thorough rinsing with hot water to remove soluble salts. Heat treatment of the bulbs and gauges in an electric oven at 500° C. for two hours sufficed to remove gases and vapors from the glass so that pressures of the order of 5×10^{-8} mm. Hg. could be obtained.

On sealing off the bulbs and gauges by melting the glass at a constriction there is a comparatively large evolution of gases and vapors which can be partly removed by pumping during the time of sealing off, but the pressure in the bulbs is always four or five times as large as the pressure before sealing off. For several days after sealing off, there is a comparatively rapid increase in pressure, after which the change in pressure is slower and is proportional to the time.

After the exhausted bulbs had stood for about two months they were subjected to further heat treatment at successively higher temperatures and the change in pressure was noted after each heat treatment. Reheating at temperatures below 250° C. resulted in only slight increase in pressure while higher temperatures produced increasingly larger changes in pressure.

A Device for the Automatic Registration of the α- and β-Particles and γ-Ray Pulses.[1]

By Alois F. Kovarik.

THE detection of individual α- or β-particles has been in all cases dependent on the visual or audible method. These methods are quite trying on the nerves, because close attention is necessary on account of the probability law of emission and long periods of counting are essential because the method is a statistical one. The method described in this paper makes it possible to get a record of individual particles on a chronograph paper, permitting a study of it at convenience, and thus enhancing the accuracy of the statistical method. The method consists in amplifying the current to the needle-point electrode in the counting chamber by means of a three electrode vacuum tube amplifier and using this current to operate a very sensitive relay which in turn operates a local battery circuit which operates the electromagnet on a chronograph. The writer wishes to express his sincere thanks to the Western Electric Co. for the fine spirit of coöperation in making him a loan of both the sensitive relay and the amplifier.

The accuracy of the method was tested (1) for the α-particles, by checking the count by the scintillation method as in previous work, (2) for the β-particles, by determining their number by a measurement of the charge carried by the β-particles and (3) by getting a record of a large number of β-particles emitted over a long time and finding the number emitted in a given interval of time and checking up, or rather, in the case of the β-particles, proving the application of the law of probability to the emission of the β-particles. To

[1] Abstract of a paper presented at the Baltimore meeting of the American Physical Society, December 28, 1918.

the writer's knowledge, this is the first automatic record of any random distribution which could be readily applied to test the probability law.

A record of the γ-rays is also obtained. The writer is not ready, at present to say that it is the γ-ray pulses which are registered although evidence seems to point that way. The law of inverse square distance (absorption in air for penetrating γ-rays neglected) is verified.

SHEFFIELD SCIENTIFIC SCHOOL,
YALE UNIVERSITY,
NEW HAVEN, CONN.,
November 23, 1918.

PHOTOELECTRIC SENSITIVITY *vs.* CURRENT RECTIFICATION IN MOLYBDENITE.[1]

BY W. W. COBLENTZ AND LOUISE S. MCDOWELL.

IN the course of an investigation of the spectral photoelectric sensitivity of molybdenite[2] it was found that samples which are sensitive photoelectrically have a considerably higher electrical resistance (100 to 1,000 times greater) than samples which are not sensitive to light. Moreover, the conductivity of the insensitive samples was found to be quite independent of the direction in which the current passed (lengthwise) through the crystal.

On the other hand, samples of molybdenite which are sensitive photoelectrically were found to possess a much higher conductivity when the electric current (from a 4-volt battery) was passed in one direction than when it was passed in the opposite direction through the crystal. This difference in current leakage ("dark current") as dependent upon the direction of the current through the crystal, varied from 10 to 30 per cent., for different crystals. The photoelectric current was therefore proportionately increased by connecting the crystal into the battery circuit in the proper direction to obtain the maximum conductivity.

It was, therefore, of interest to determine whether any relation exists between photoelectric sensitivity and the rectifying action which occurs when the crystal is placed in a high frequency oscillating circuit.

For this purpose crystals (size 10 by 4 by 0.1 mm.) were selected which showed one or two small photoelectrically sensitive spots, but which were quite insensitive throughout the remainder (of the surface) of the crystal.

The rectification tests were made by means of an ordinary tuned buzzer circuit. The telephone and detector, in series, were placed in parallel with the condenser of the secondary circuit. The coupling was adjusted to produce strong oscillations in the secondary circuit. The molybdenite crystal was explored for rectification by touching the surfaces by means of a fine metal point.

The results of these tests show that the low-resistance, photoelectrically-

[1] Abstract of a paper presented at the Baltimore meeting of the American Physical Society, December 27, 1918.

[2] PHYS. REV., 11, p. 497, 1918.

insensitive samples of molybdenite are far more efficient rectifiers than the high-resistance, light-sensitive specimens. One such specimen, which showed no photoelectric sensitiveness whatever, as determined by a sensitive galvanometer, produced decided rectification over almost its entire surface. In fact it was difficult to find a spot which produced no rectification. On the other hand, the samples of molybdenite, having a high resistance exhibited the rectifying action only in spots, which usually did not coincide with the photoelectrically sensitive spots. These radio-electrically sensitive spots were widely scattered over the surface, but sometimes comparatively large areas were found which showed no electrical rectification, as indicated by the telephone. Only the most sensitive spots of the high resistance material produced a rectification approaching that of the specimens having a low resistance.

In two instances, especially electrically sensitive spots were found upon the light-sensitive areas, but other, equally sensitive spots occurred in the areas which were photoelectrically insensitive.

The conclusions to be drawn are therefore that: (1) the low-resistance, photoelectrically-insensitive molybdenite exhibits much greater rectifying action than the high-resistance, photoelectrically-sensitive specimens; (2) there is no apparent relation between the electrical rectification and the photoelectric sensitivity observed in molybdenite.

BUREAU OF STANDARDS,
November 9, 1918.

ABSORPTION COEFFICIENT OF THE PENETRATING RADIATION.[1]

BY OLIVER H. GISH.

IT is stated several times in the literature that the "penetrating radiation of the atmosphere" has much greater penetrating power than the hardest γ-rays but no attempts to measure this directly have been made previously.

The following table gives values obtained indirectly from Kohlhörster's observations.

Absorption Coefficient in Air (Computed).

Altitude, *m.*	Absorption Coef. (μ) (Computed) ($Cm.^{-1}$).	Absorption Coef. of γ-Rays in Air Divided by μ.	Observer.
- - - -	1.10×10^{-5}	4.8	Kohlhörster
111- 686	1.53 "	3.4	Gish
3861-9071	0.772 "	6.8	"
- - - -	0.746 "	7.0	E. v. Schweidler

Using a Wulf type electroscope in the form of a vertical cylinder and adding concentric cylinders of lead at intervals the following results were obtained.

[1] Abstract of a paper presented at the Baltimore meeting of the American Physical Society, December 28, 1918.

Absorption Coefficient in Lead (Measured).

Altitude, m.	Absorption Coef. (μ) (Measured) ($Cm.^{-1}$).	Absorption Coef. γ-Rays in Lead $\div \mu$.	Place.
359	1.22	0.41	Lincoln, Nebr.
1857	0.82	0.61	Colorado Spr's, Colo.
4308	0.45	1.11	Pike's Peak

The values in the first table are less than those found for gamma-rays (6.0×10^{-5}) while those in the second table are (except for the last) greater than the coefficient of absorption of gamma-rays in lead (0.50). It should however be said that in the latter case the values obtained are too large due to the method of computing them. Both tables are however significant in that they show a decrease in the absorption coefficient with altitude. In view of this it seems probable that the "upper component" of the penetrating radiation is more penetrating than gamma-rays.

WESTINGHOUSE RESEARCH LABORATORY,
EAST PITTSBURGH, PA.

IONIZATION AND RESONANCE POTENTIALS FOR ELECTRONS IN VAPORS OF ARSENIC, RUBIDIUM, AND CÆSIUM.

BY PAUL D. FOOTE, O. ROGNLEY AND F. L. MOHLER.

THE study of electron currents in metallic vapors has been extended to arsenic, rubidium and cæsium. The resonance potential or potential of inelastic impact and ionization potential were measured by the method used in previous work.

The results with arsenic gave the resonance potential at 4.7 volts and ionization at 11.5 volts. As these values are close to the corresponding potentials for mercury of 4.9 volts and 10.3 volts the experiment was repeated with all possible precautions with similar results. A wehnelt discharge showed no visible arc with a current of 30 milliamperes but when some mercury was added to the arsenic the arc was visible with a current of .02 milliampere. In the case of metallic vapors so far studied the quantum relation $Ve = h\nu$ shows these potentials to be related to the frequencies of the first line and limit of a prominent series in the spectrum of the metal. No such relation can be found in the case of arsenic but little is known of series relations in arsenic.

The potentials found may predict a series with its first line and limit near $\lambda = 2{,}620$ and $\lambda = 1{,}070$ respectively.

In rubidium vapor the resonance potential is 1.6 volts and the ionization potential 4.1 volts, in cæsium 1.48 volts and 3.9 volts respectively. Tate and Foote[2] have shown that in the case of sodium and potassium these potentials are determined from the quantum relation $Ve = h\nu$ by the frequencies of the first line and limit of the principal series.

[1] Abstract of a paper presented at the Baltimore meeting of the American Physical Society, December 28, 1918.

[2] Phil. Mag., 36, p. 75, 1918.

These series in the case of rubidium and cæsium are widely separated doublets. Foote and Mohler[1] found in the case of thallium that the short wave-length line of the doublet determined the value of the resonance potential. The accompanying table shows that the series relations of rubidium and cæsium are analogous to sodium and potassium. The agreement is well within experimental error if we take as in the case of thallium the short wave-length line of the doublet.

Resonance and Ionization Potentials for the Alkali Metals.

Metal.	$\lambda(\text{Å})$ $(p = 1.5\ s - 2p)$.	Resonance Potential Volts.		$\lambda(\text{Å})$ $(p = 1.5\ s)$.	Ionization Potential Volts.	
		Computed.	Observed.		Computed.	Observed.
Lithium.....	6707.85	1.839	——	2299.67	5.363	——
Sodium.....	5895.94 5889.97	2.092 2.094	2.12	2412.63	5.112	5.13
Potassium.....	7699.01 7664.94	1.602 1.609	1.55	2856.69	4.318	4.1
Rubidium.....	7947.64 7800.29	1.552 1.581	1.6	2968.40	4.155	4.1
Cæsium.....	8943.46 8521.12	1.379 1.447	1.48	3184.28	3.873	3.9

BUREAU OF STANDARDS,
WASHINGTON, D. C.
December 9, 1918.

NOTE ON THE DISTRIBUTION OF ENERGY IN THE VISIBLE SPECTRUM OF A CYLINDRICAL ACETYLENE FLAME.[2]

BY EDW. P. HYDE, W. E. FORSYTHE AND F. E. CADY.

A KNOWLEDGE of the distribution of energy in the visible spectrum of an acetylene flame has become important within the last few years through the use of this flame, in cylindrical form, in investigations of the visibility of radiation. It can be shown by computation that the data on acetylene published by Coblentz form a curve in the visible spectrum which will not agree with that of a black body at any temperature to better than 7 or 8 per cent. As this would mean that no color match could be obtained and as previous experience of the authors had led to the conclusion that the energy curve of acetylene differed in shape from that of a black body only in the extreme red, a short investigation was undertaken to verify this conclusion.

Tungsten lamps whose current color-temperature relation was carefully determined in this laboratory, were sent to the Eastman Kodak Company and to the Bureau of Standards with the request that they be compared with the

[1] PHYS. REV., 11, p. 487, 1918.

[2] Abstract of a paper presented at the Baltimore meeting of the American Physical Society, December 28, 1918.

acetylene flame and the current for color match be found. The results gave an average value of 2360° K ± 10° K., and neither laboratory reported any difficulty in obtaining a match in color. However the Bureau of Standards reported a difference amounting to about 75° K. between the flame as given by the Eastman standard burner and that given by the " Crescent Aero" burner, the latter being higher.

The spectral distribution of the flame was measured by means of a spectrophotometer and a spectral-pyrometer and the results gave a curve agreeing within the limits of error with that of a black body at 2360° K. In the extreme red, beyond 0.70 μ there was indication of a higher emissivity for the acetylene. A photographic method gave results corroborating those just mentioned.

A test of the sensibility of the color-match method to show differences in the spectral energy curve, showed that if two spectral curves matched at 0.5 μ and 0.7 μ and differed by as little as 4 per cent. in the middle of the spectrum, the two light sources could not be made to match in color.

In conclusion it is recommended that the relative emission intensities of a cylindrical acetylene flame, at least for that type represented specifically by the Eastman standard burner and for the wave-length interval from 0.4 μ to 0.7 μ should be taken as identical with those of a black body at 2360° K.

NELA RESEARCH LABORATORY,
NATIONAL LAMP WORKS OF GENERAL ELECTRIC CO.,
NELA PARK, CLEVELAND, OHIO,
December, 1918.

PRELIMINARY NOTE ON THE LUMINESCENCE OF THE RARE EARTHS.[1]

BY E. L. NICHOLS, D. T. WILBER AND F. G. WICK.

THE rare earths in solid solution in CaO and certain other media exhibit fluorescence and absorption of special interest on account of the narrow bands in their spectra.

By experiments now in progress we have established the following points:

1. All bands visible when luminescence is excited by the iron spark coincide precisely with the bands of kathodo-luminescence. It is probable therefore that, as in the case of the uranyl salts, willemite, etc., the location of bands is independent of the mode of excitation.

2. When excited at the temperature of liquid air, these spectra undergo a marked narrowing of the bands and, particularly in the blue and violet, broad hazy bands are resolved into numerous line like components.

3. At low temperatures the bands usually ascribed to erbium in the blue appear to be greatly enhanced whereas the bands due to samarium, chiefly in the red, are weakened. In preparations containing both of these elements, the change in the color of fluorescence thus produced is very striking.

4. Since bands due to several elements are present in all preparations thus

[1] Abstract of a paper presented at the Baltimore meeting of the American Physical Society, December 28, 1918.

far made, the search for series is greatly complicated. There is evidence however of the occurrence of constant frequency intervals, as in the case of all other fluorescent substances thus far examined.

On the Critical Absorption Frequencies of Chemical Elements of High Atomic Numbers.[1]

By William Duane and Takeo Shimizu.

In several papers[2] presented to the American Physical Society accounts have been given of measurements of the critical X-ray absorption frequencies of some of the chemical elements. In making these measurements an X-ray spectrometer with a calcite crystal has been employed. Before striking the crystal the X-rays passed through two narrow slits and after reflection through a third slit in front of the ionization chamber, which was wide enough to admit the entire reflected beam of X-rays into the chamber. This arrangement makes a large correction for the absorption of the X-rays by the crystal unnecessary. The critical absorption wave-lengths were obtained by drawing curves representing the ionization currents as functions of the angle made by the crystal planes with the X-ray beams (the grazing angles of incidence). If a thin sheet of a chemical element (or of one of its compounds) is placed in the path of the X-rays, a marked break in the curve appears at a certain point. The ionization current on the high frequency side of this break is much smaller than on the low frequency side, indicating a substantial increase in the absorption of the shorter X-rays by the chemical element. The formula

$$\lambda = 6.056 \sin\theta \times 10^{-8} \text{ cm.} \qquad (1)$$

gives the wave-length λ, in which the double grazing angle is obtained by measuring from the center of the sharp drop in the ionization curve on one side of the zero line of the spectrometer to that on the other side.

The papers above referred to contain the results of experiments on chemical elements up to and including cerium, with an atomic number of 58. The present paper deals with an extension of the measurements to chemical elements of atomic numbers higher than 58. We used the same apparatus as in the previous researches with the single exception that the current exciting the X-ray tube came from a high tension transformer (with a system of kenotrons and condensors, etc., to give approximately a constant difference of potential), instead of from the high tension storage battery previously employed. With this apparatus we have measured the critical absorption frequencies for a num-

[1] Abstract of a paper presented at the Baltimore meeting of the American Physical Society December 28, 1918.

[2] The Critical Absorption of Some of the Elements for High Frequency X-rays, F. C. Blake and William Duane, Phys. Rev., December, 1917. On the Relation between the K X-ray series and the Atomic Numbers of the Chemical Elements, William Duane and Kang-Fuh Hu, Phys. Rev., June, 1918. On the Critical Absorption and Characteristic Emission X-ray Frequencies, William Duane and Kang-Fuh Hu, Phys. Rev., June, 1918.

ber of chemical elements up to mercury (atomic number 80). The lantern slides shown indicate that the square roots of these frequencies plotted against the atomic numbers depart from the straight line law to a still greater extent than the measurements previously recorded for chemical elements of lower atomic numbers.

In one of the papers referred to it was shown that the velocity v of the electron required to produce the K characteristic X-rays, calculated from the simple formula

$$h\nu = \frac{1}{2}\frac{mv^2}{\sqrt{1-\frac{v^2}{c^2}}}, \tag{2}$$

is a linear function of the atomic number N, it being given by the equation

$$v = 0.00678c(N - 3/2) \tag{3}$$

to within about 1/5 per cent. up to the atomic number 58. As indicated by the lantern slide shown the departure from this law for chemical elements up to mercury ($N = 80$) amounts to only 1 per cent.

We have plotted on the same diagram the results of the interesting experiments recently published by de Broglie. He used a photographic method for measuring the critical absorption wave-lengths. The correction for the absorption by the crystal in this method does not appear to be quite clear, especially as the correction must depend upon the finite size of the crystal. As a matter of fact the velocities we have calculated from his data by equation (2) fall about as far above the straight line represented by equation (3) as our values do below it.

In dealing with these chemical elements of high atomic numbers we must remember that the velocities of the electrons required to produce their characteristic X-rays exceed half the velocity of light, and that several formulas have been proposed for the electron's kinetic energy. The velocities calculated by these formulas differ from each other (in the case of mercury for instance) by several per cent. We postpone a discussion of these points, however, until the critical frequencies for radium, thorium and uranium have been obtained.

SOME INTERESTING RESULTS OF ECLIPSE MAGNETIC OBSERVATIONS.[1]

BY L. A. BAUER.

BECAUSE of the bearing of a definite detection of magnetic effects during solar eclipses upon theories of magnetic variations, the Department of Terrestrial Magnetism of the Carnegie Institution of Washington made special arrangements for magnetic and allied observations during the solar eclipse of June 8, 1918. In the program of work, there participated magnetic observa-

[1] Abstract of a paper presented at the Baltimore meeting of the American Physical Society, December 28, 1918.

tories and universities distributed over the entire zone of visibility, from China and Japan to the Atlantic seaboard. There were thus obtained magnetic data from about twenty-five stations.

The results gained confirm the general conclusions reached from similar observations made in accordance with the author's scheme of observation during various eclipses since 1900. It may now be regarded as definitely proved that during a solar eclipse the earth's magnetic field passes through a minute oscillation, the period of which approximates that of the eclipse and the range of which, as compared with that of the solar diurnal magnetic variation, is approximately proportional to the amount of sunlight and other solar radiations cut off from the earth by the moon.

The character of the magnetic effect during the eclipse is in general the reverse of that which occurs during the sunlit hours of the day. Its main characteristic features occur from station to station not according to absolute time, nor to local time but according to eclipse time, as of course should be the case if the effect is attributable to the eclipse.

The range of the effect on the magnetic declination is about 0.1 of that of the solar-diurnal variation, or about one minute of arc for our latitudes. The maximum effect on the strength of the earth's magnetic field is about 0.03 per cent., or equivalent to the effect found by the author for a ten per cent. change in the solar radiation as revealed by changes in the solar-constant values observed at Mt. Wilson by the Smithsonion Institution.

The mathematical analysis of the eclipse magnetic variation may throw light upon the causes of other variations of the earth's magnetic field, notably of those attributed to the sun and moon. Fuller publication will be found in the Journal of Terrestrial Magnetism and Atmospheric Electricity, Vols. 23 and 24.

Why Clouds Never Form in the Stratosphere.[1]

By W. J. Humphreys.

IT is obvious from the occurrence of cirrus clouds at the base of the stratosphere that at this level the atmosphere frequently is fully saturated. We should, therefore, expect the stratosphere, even if wholly free from vertical convection, to become humid through long continued diffusion. Nevertheless clouds do not form in it even under the influence of rapid drops in temperature of 10° C. or more. It must, therefore, have a humidity far below saturation. And to this condition there are at least two contributing causes.

(*a*) In the absence of vertical convection the vapor pressure must rapidly decrease, under the influence of gravity, with elevation, just as does the pressure of the atmosphere as a whole. Hence, at anything like constant temperature, the stratosphere, even if saturated at the base, must rapidly become very dry with increase of elevation. But this is not sufficient to account for the total absence of clouds at these levels.

[1] Abstract of a paper presented (by title) at the Baltimore meeting of the American Physical Society, December 27, 1918.

(*b*) The lower portion of the stratosphere normally has a minimum temperature during the passage of each anticyclone which obviously prevents water vapor from diffusing upward to a greater density at any level than that of saturation at this low temperature. The little vapor that does diffuse a short ways upward during the few days prevalence of any milder temperatures, such as accompany cyclonic conditions, is precipitated on the passage—never long delayed—of the next anticyclone. In this way the stratosphere is kept exceedingly dry, and clear skies instead of hazy made the rule for anticyclonic weather.

THE MINIMUM TEMPERATURE AT THE BASE OF THE STRATOSPHERE.[1]

BY W. J. HUMPHREYS.

NUMEROUS records obtained by sounding balloons have shown conclusively that, on the average, the temperature at the base of the stratosphere is lower than at any other level, above or below.

As this is not in accord with a state of thermal equilibrium one naturally looks for the cause in some type of forced convection.

An analysis of the records shows that this minimum temperature is especially pronounced in anticyclonic regions, or where the barometric pressure is high. But in these regions the chief flow of the atmosphere is towards lower latitudes. Hence it lags, or loses some of its eastward velocity, and thereby interferes with the flow of the prevailing winds from the west and causes them to rise, as over a mountain barrier, to unwonted heights, and thus to cool to abnormally low temperatures.

The base of the stratosphere recovers somewhat from its minimum temperature after the passage of an anticyclone, but only to be again dynamically cooled below the point of radiation equilibrium by the next anticyclone, and so on indefinitely.,

On the average, therefore, the lower portion of the stratosphere has a mechanically enforced minimum temperature more or less below the point of radiation equilibrium.

STRIÆ IN OPTICAL GLASS.[1]

BY L. E. DODD AND A. R. PAYNE.

VARIOUS types of striæ in optical glass, classified on the basis of visible appearance, are described, and photographs shown. Certain of these types are then discussed from the standpoint of their nature and probable origin. A relationship between gas bubbles in the glass and striæ is pointed out. The application of pressure to the molten glass is advocated as a preventive, not only of bubbles, but also of those striæ associated with bubbles. Another probable source of the more numerous striæ is given as the separation

[1] Abstract of a paper presented (by title) at the Baltimore meeting of the American Physical Society, December 27, 1918.

of lead or its oxide, in the lead glasses. Striæ having such origin, however, are more localized, near the walls and bottom of the pot, and may be reduced to a minimum in number by proper heat treatment and stirring. It is thought that striæ in the more central part of the glass mass in the pot, which are regarded as being mostly associated with bubbles, may be largely prevented by application of pressure, and that thereby the per cent. of good glass may be considerably raised from the present amount of 20 or 25 per cent. of the total melt. The experimental application of pressure is proposed as a special research, primarily of commercial value, but indirectly of scientific value by its possibility of opening the way to the manufacture of the larger lenses free from defect.

BUREAU OF STANDARDS,
PITTSBURGH BRANCH.

EFFECT OF CRYSTAL STRUCTURE UPON PHOTOELECTRIC SENSITIVITY.[1]

BY W. W. COBLENTZ.

IN a previous investigation[2] it was observed that plates of silver sulphide which had been prepared in the laboratory and subjected to hammering, were rather insensitive photoelectrically. On the other hand, the natural mineral acanthite, Ag_2S is sensitive photoelectrically. The sample tested was a spindle-shaped rod about 8 mm. long, irregular in outline, and consisting principally of three crystals. Wishing to produce a wider receiving surface for spectral photoelectric examination, the central crystal was flattened by hammering. It was then found that this flattened crystal was quite insensitive photoelectrically, whereas, the rest of the material remained sensitive. Evidently the change in internal configuration of the crystal had some effect upon the photoelectric sensitivity. It is, therefore, proposed to observe the spectral photoelectrical sensitivity of the sample before and after mechanical manipulation.

BUREAU OF STANDARDS,
WASHINGTON, D. C.,
December 27, 1918.

SILVERING QUARTZ FIBERS BY CATHODIC SPUTTERING.[1]

BY J. E. SHRADER.

THE device by Williams[3] for silvering quartz fibers has been so modified that the measurement of the resistance of the fibers can be measured in situ.

Sputtering of fibers has been done with D.C. from generators, rectified A.C. from a transformer, and A.C. from a transformer rectified only by the sputter-

[1] Abstract of a paper presented (by title) at the Baltimore meeting of the American Physical Society, December 27, 1918.

[2] Bull. Bur. Standards, 14, p. 591, 1918.

[3] PHYS. REV., 4, pp. 517, December, 1914.

ing device itself. The sputtering was done in hydrogen at different voltages and current densities, while the resistance was measured for varying lengths of time of sputtering.

After silvering the resistance of the fiber has been observed to change with time and this change has been measured over a short period of time.

ON THE CHARACTERISTICS OF ELECTRICALLY OPERATED TUNING FORKS.[1]

BY H. M. DADOURIAN.

THE communication presents the results of a series of experiments performed to determine the conditions affecting the frequency of electrical tuning forks. Detailed descriptions of the experiments will be published in an early issue of THE PHYSICAL REVIEW.

PALMER PHYSICAL LABORATORY,
PRINCETON UNIVERSITY,
December 10, 1918.

A MECHANICALLY BLOWN WIND INSTRUMENT.[1]

BY A. G. WEBSTER.

THE principle employed is that of the squeaky faucet or fluttering safety-valve. A spring of variable tension holds the valve in place and the proper pressure causes a puff of air, which generates a sound wave in the horn, which on reflexion arrives at the valve in the proper phase to maintain vibration. The theory, combined with the author's theory of acoustical impedance, leads to a new boundary problem in partial differential equations.

THE DYNAMICS OF THE RIFLE FIRED AT THE SHOULDER.[1]

BY A. G. WEBSTER.

A RECORD is made on a smoked glass attached to a rifle in the act of being fired. From this, the acceleration of the gun may be calculated and thus the elastic properties of the shoulder determined. Experiments are made with various rifles, including the Browning Machine Gun.

INTERIOR BALLISTICS, BY A NEW GUN INDICATOR.[1]

BY A. G. WEBSTER.

AN indicator is described in which the stiffness of the spring is so great and the damping so perfect that oscillations due to the apparatus are eliminated. Results obtained regarding the burning of the powder are described.

[1] Abstract of a paper presented at the Baltimore meeting of the American Physical Society, December 28, 1918.